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System Analysis of Pb-Bi Cooled Fast Reactor PEACER

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Nuclear Integrated Design Engineering Analysis

NuIDEA

SEOUL NATIONAL UNIVERSITY

PEACER Design Focus

Proliferation-Resistance
- Tech. & institutional barriers

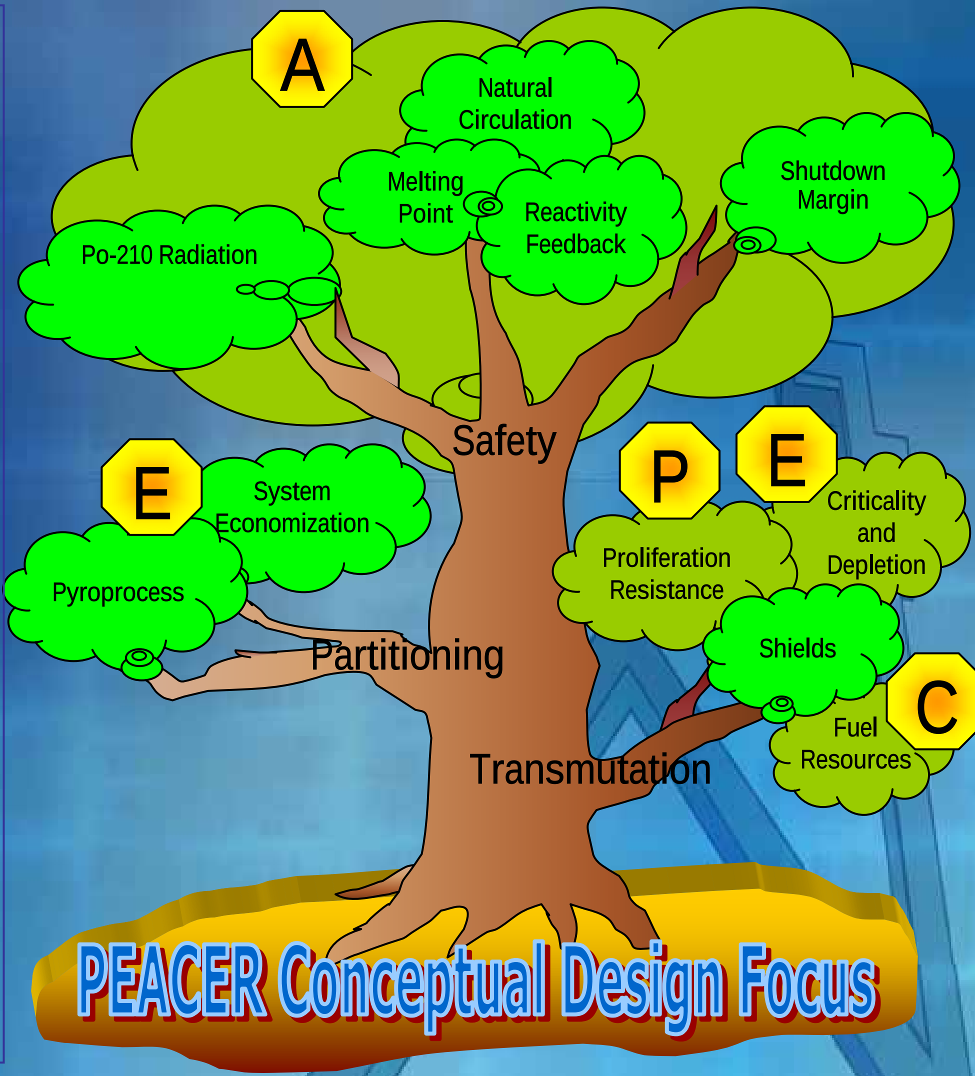
Environment-Friendliness
- Transmutation

Accident-Tolerance
- Pb-Bi coolant

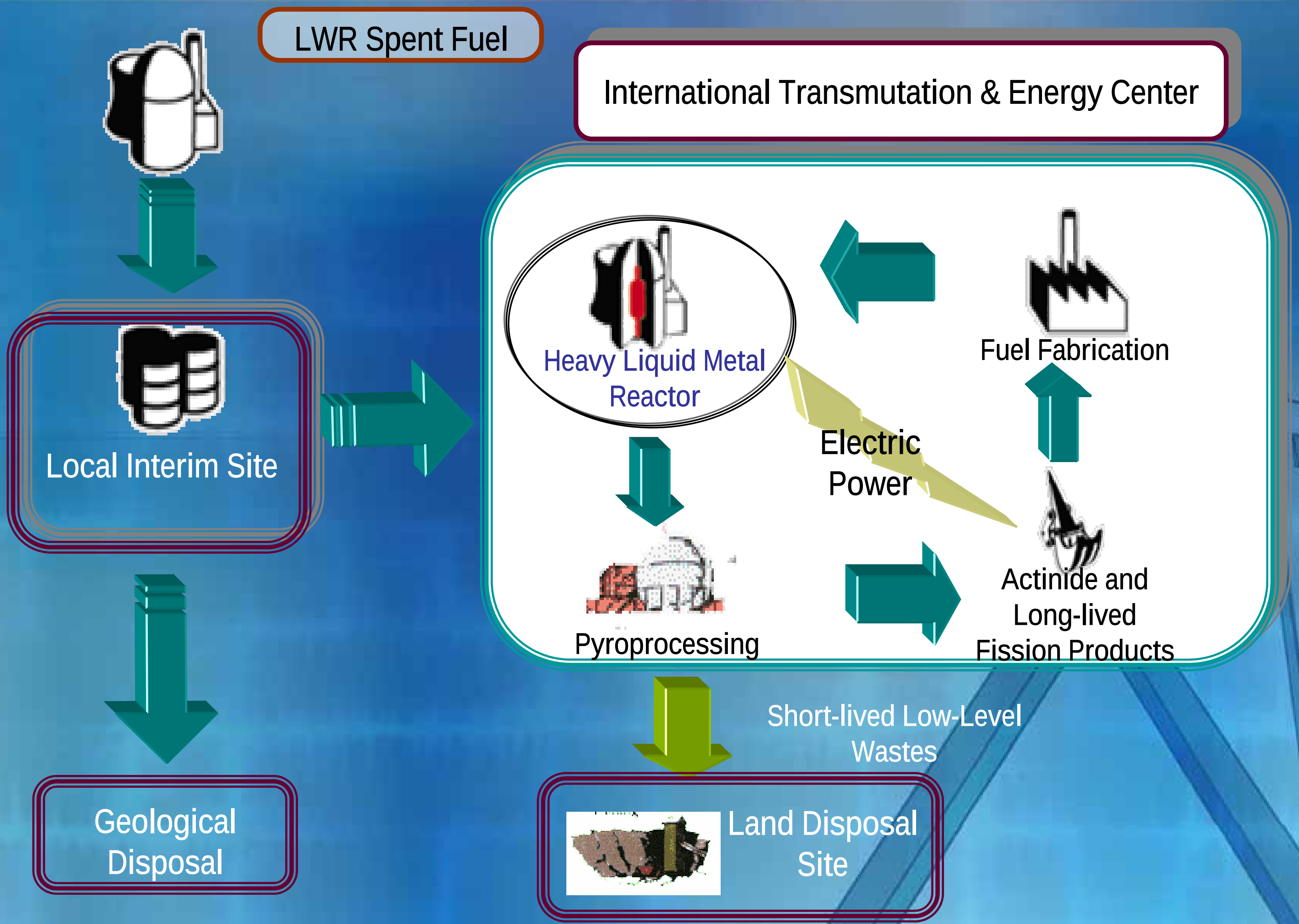
Continuable-Energy
- U & Th fuel

Economical
- Cheap pyroprocessing

Reactor
- Critical



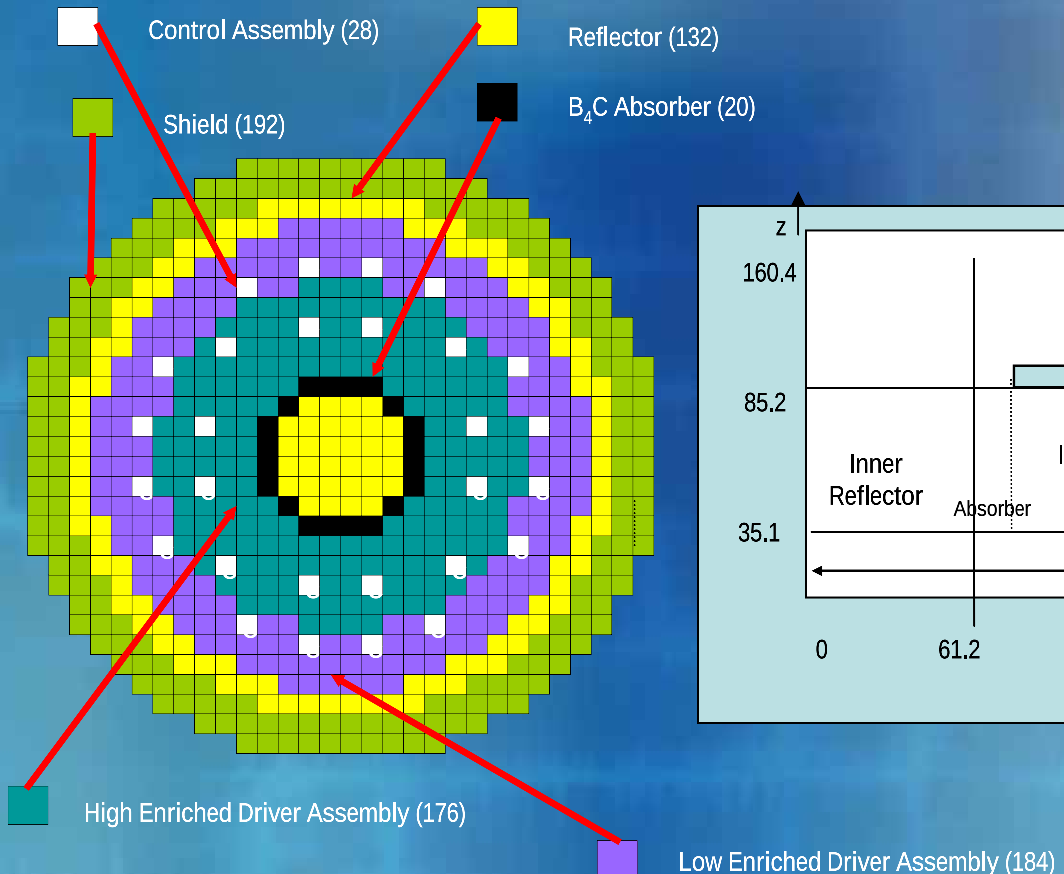
PEACER for Transmutation & Energy



System Design Parameters

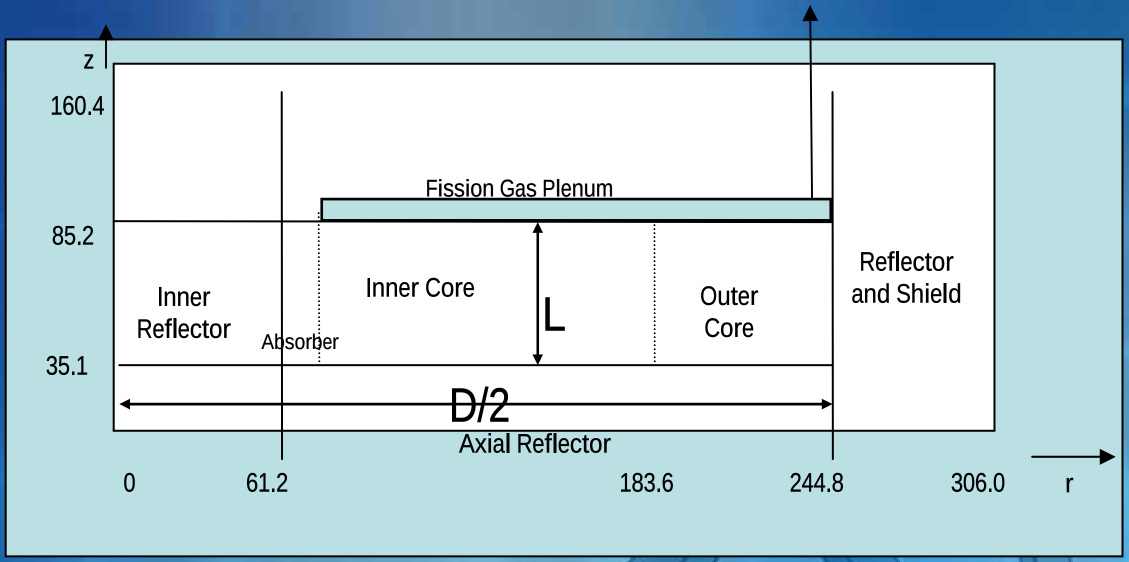
Thermal Power [MWth]	1,560	Cycle Length [day]	365
Electric Power [MWe]	550	Capacity Factor [%]	90
Thermal Efficiency [%]	35	Fuel Composition	U-TRU-Zr (57.2-31.9-10.9)
Coolant	Pb-Bi	Smeared Density [%]	67 (≤73)
Control Assembly	B_4C	Enrichment Zones	2
EFPD [day]	330	Cladding Material	HT-9

Reactor Core Design



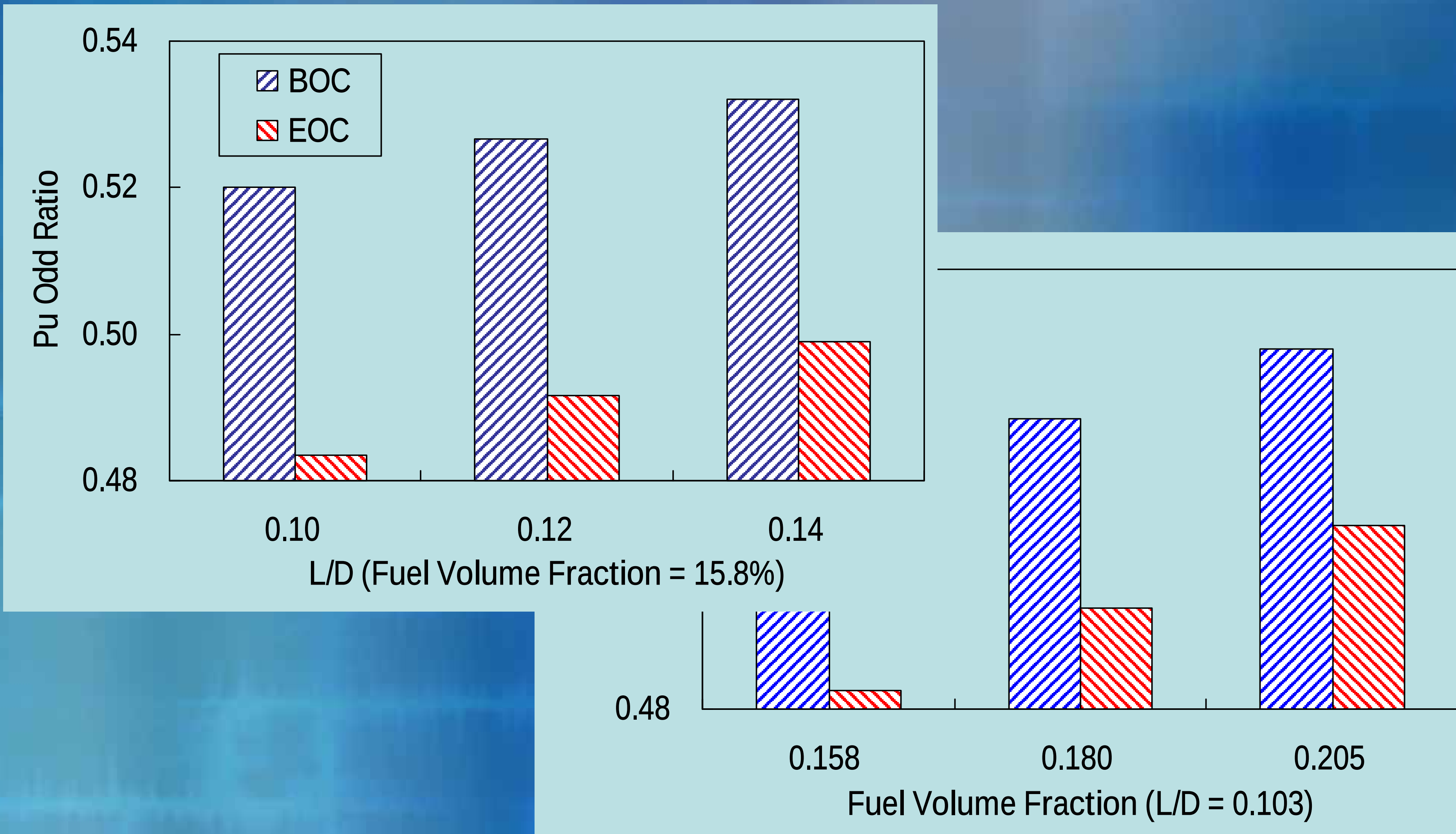
Cross-sectional View

Tc loading, 15 cm high



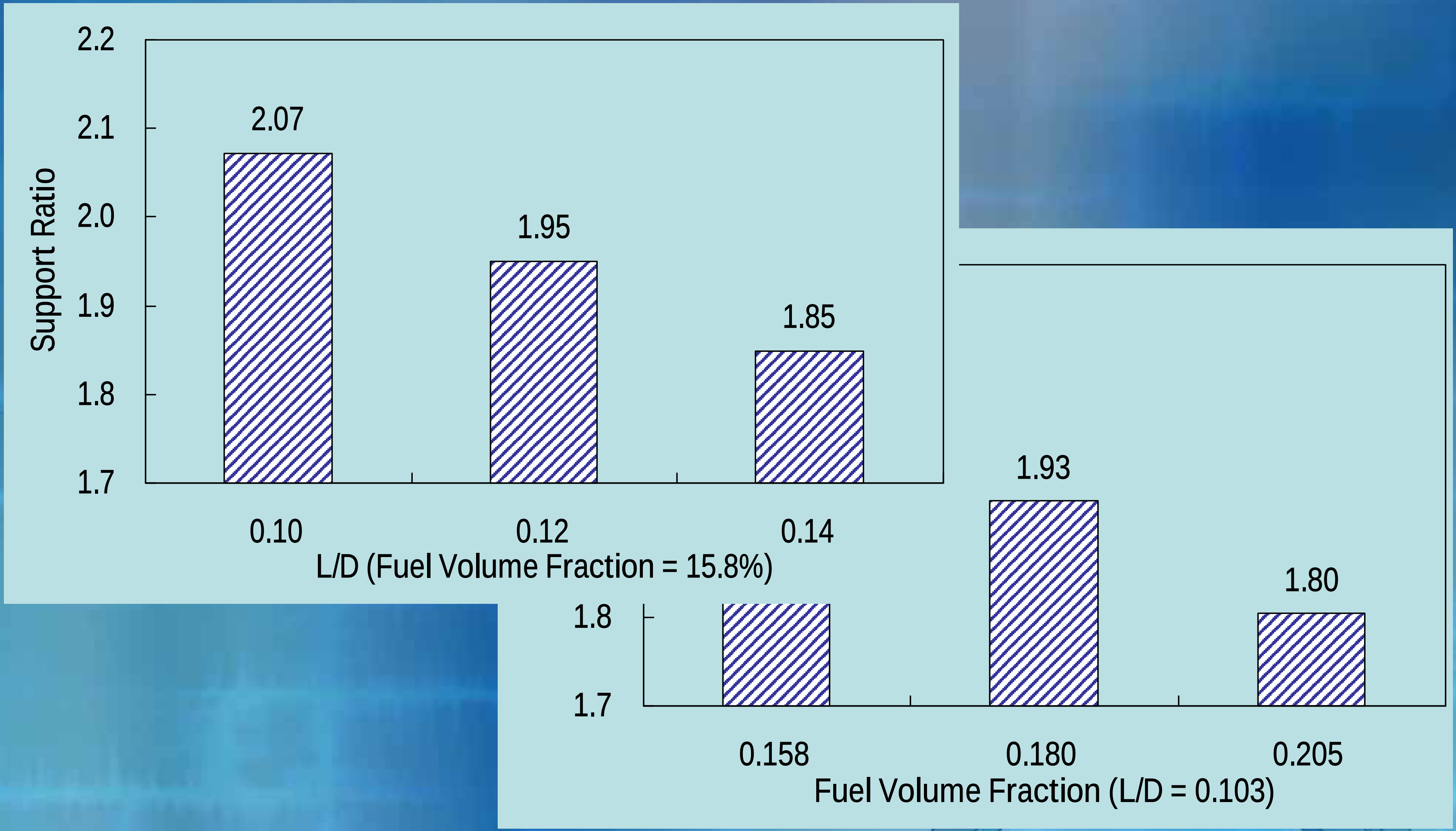
Side View (unit: cm)

Proliferation-Resistance



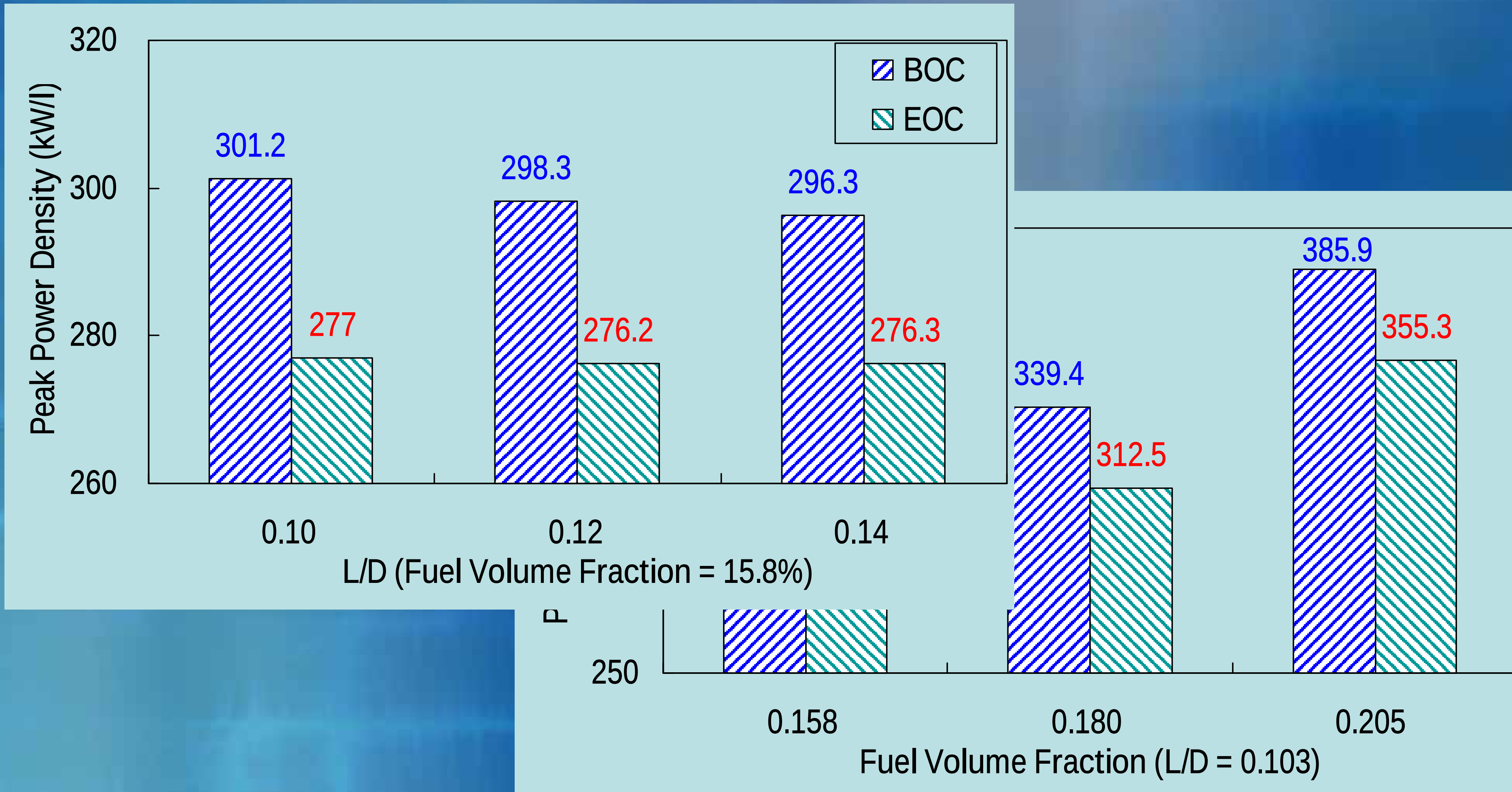
Goal for OR(<0.5) is achieved at low L/D and fuel volume fraction

Environment-Friendliness



Goal for SR(>2.0) is achieved at low L/D and fuel volume fraction

Accident-Tolerance



- Peak power density is low at 50% of the current Na-cooled reactor
  - Peak power density decreases with fuel volume fraction

Transient Analysis

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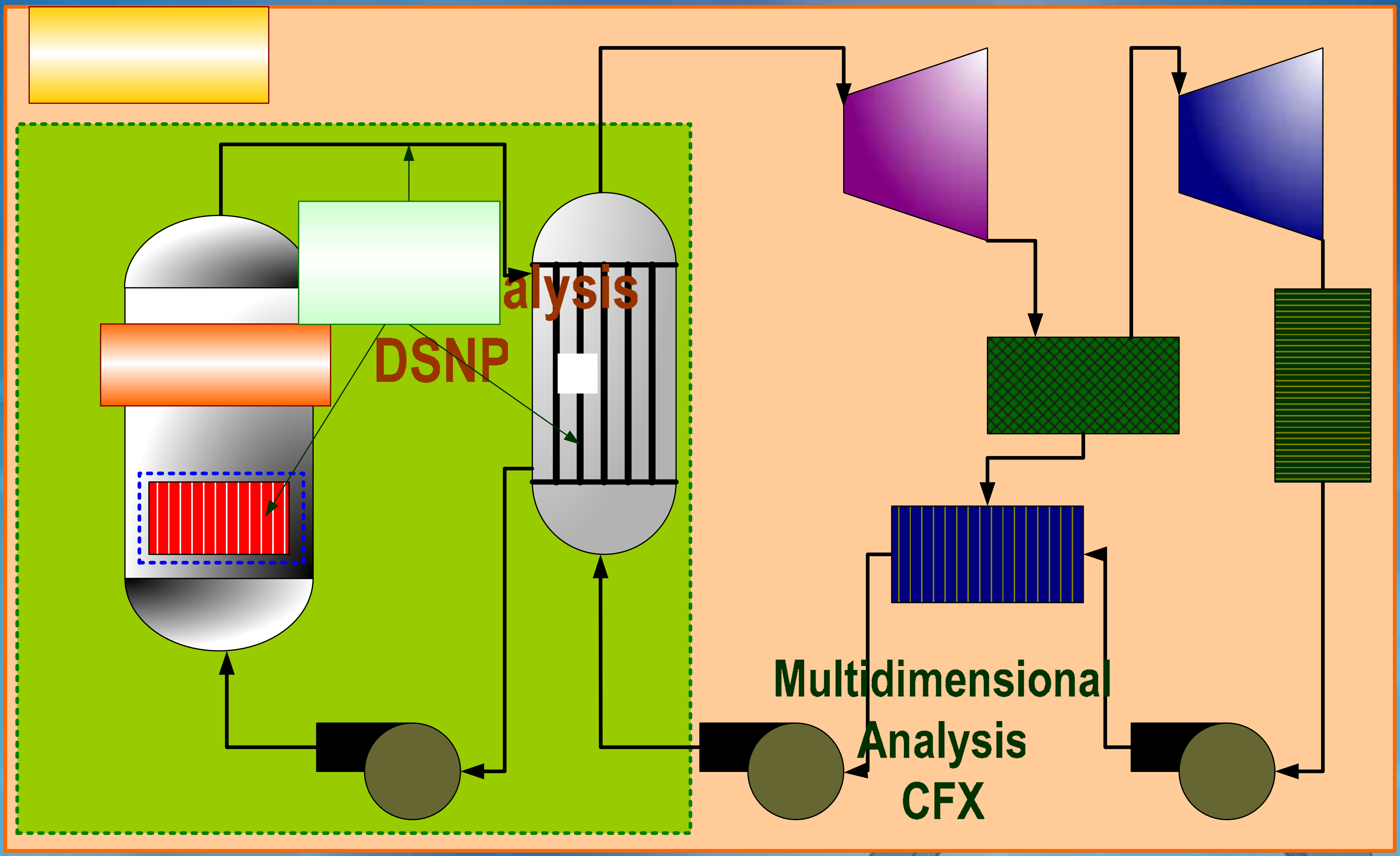
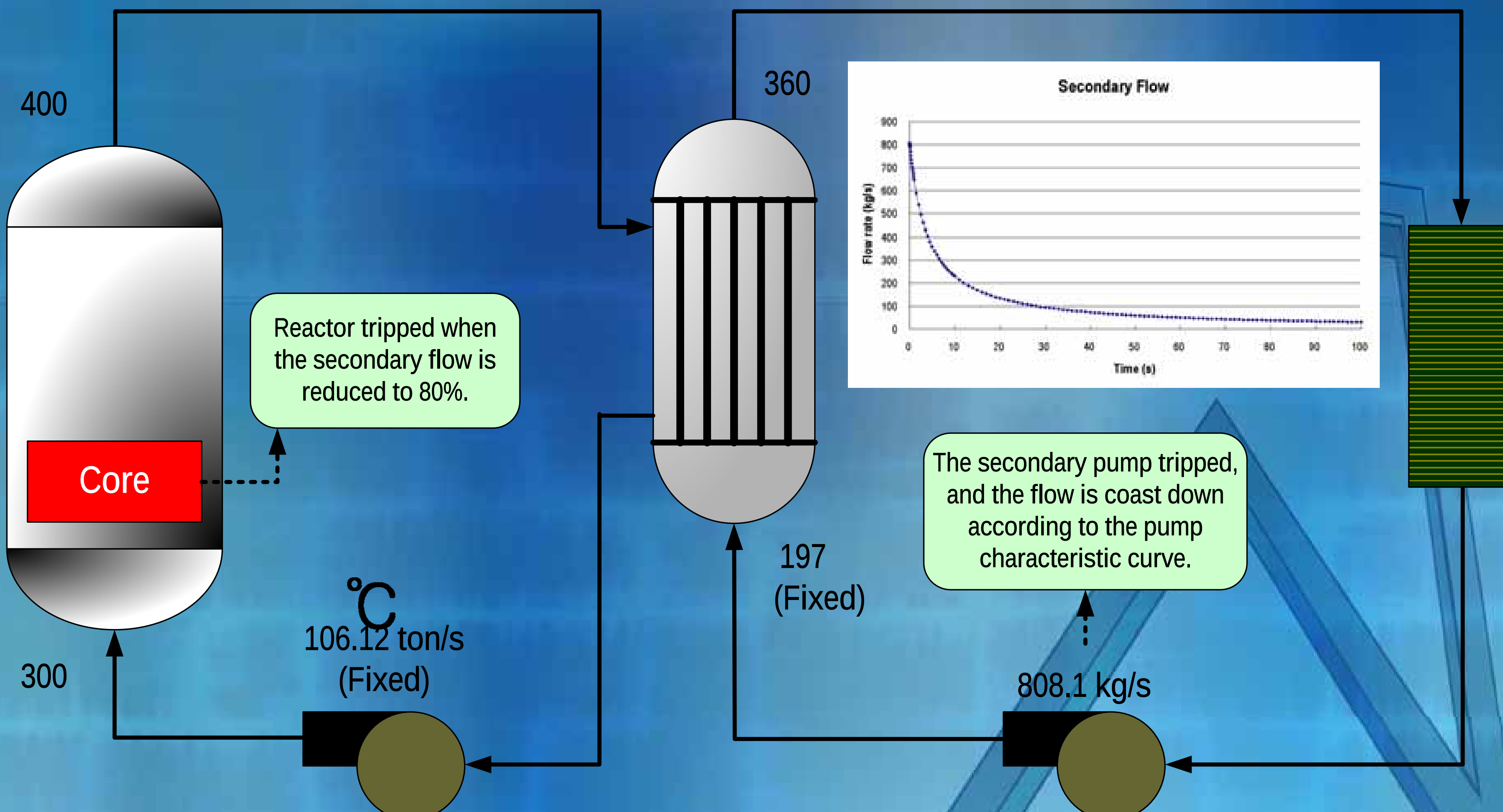
Analysis Domain

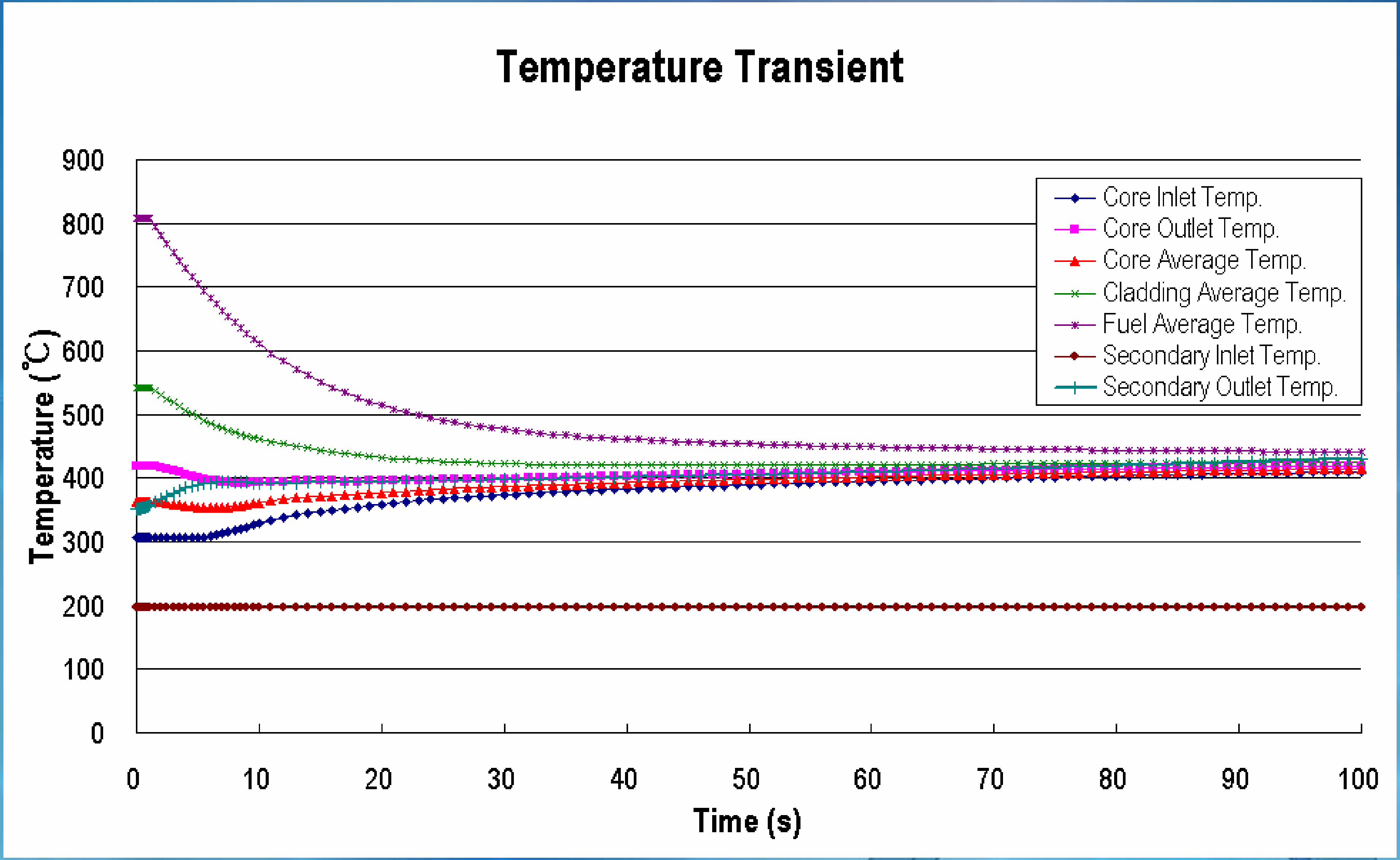


Problem Definition

Loss of Heat Sink



Temperature Transient

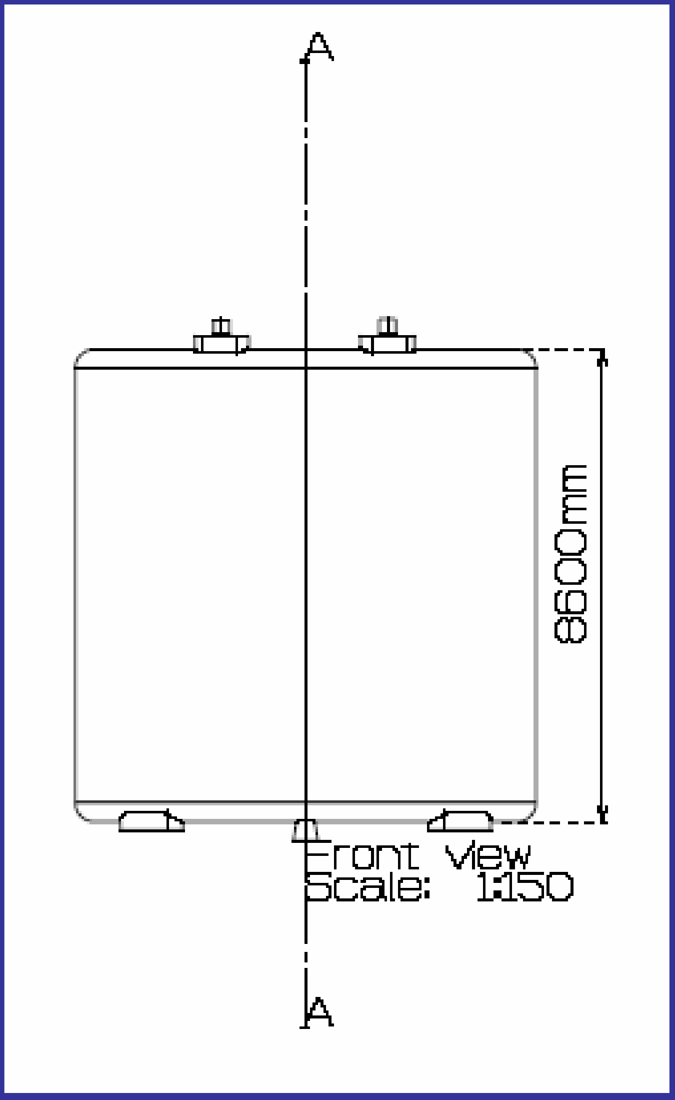


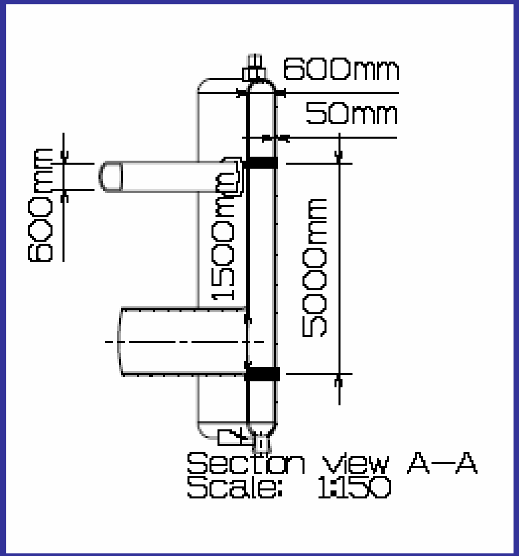
Design Shakedown

PEACER-300 Design

	PEACER-550	PEACER-300
Thermal Power	1560 MWth (550 MWe)	850 MWth (300 MWe)
Fuel Assembly	14x14 (360 assemblies)	17x17 (252 assemblies)
Passive Safety System	Natural Circulation	Natural Circulation and Reactor Vessel Aux Cooling System
Steam Generator	Cylindrical Shape	Bucket Shape

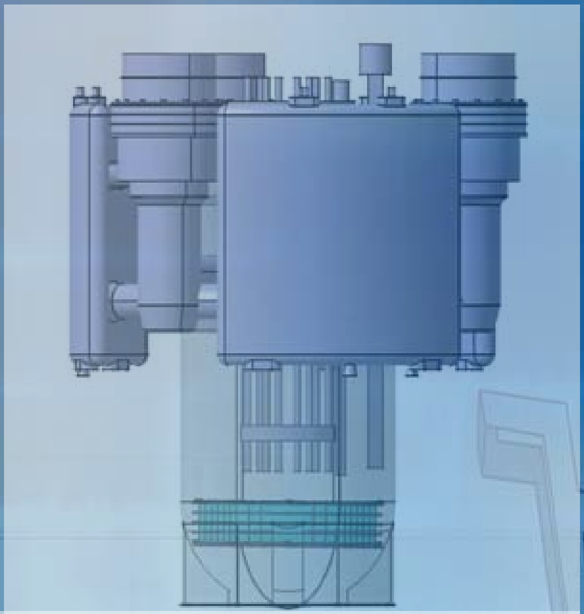
Schematic of Steam Generator

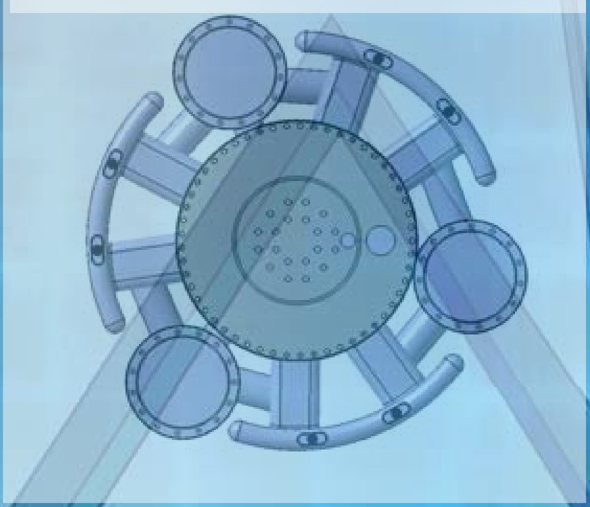




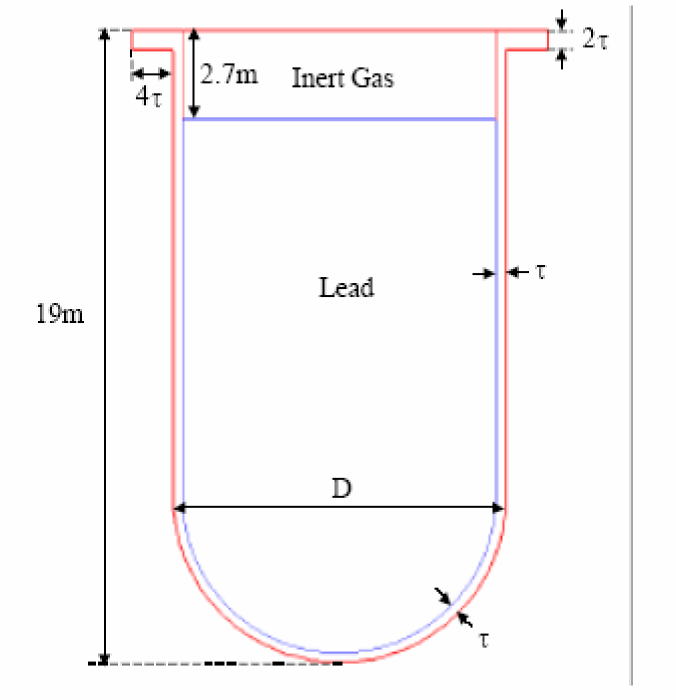
Geometry	Design Value
Pressure [MPa]	8
Number of Loops	3
Number of Tubes per Unit	9,853
Tube Length [m]	5
P/D, Tube Outer/Inner Diameter [mm]	1.2, 20/16
Mass Flow Rate [kg/s]	19,353
Feedwater Mass Flow Rate [kg/s]	146

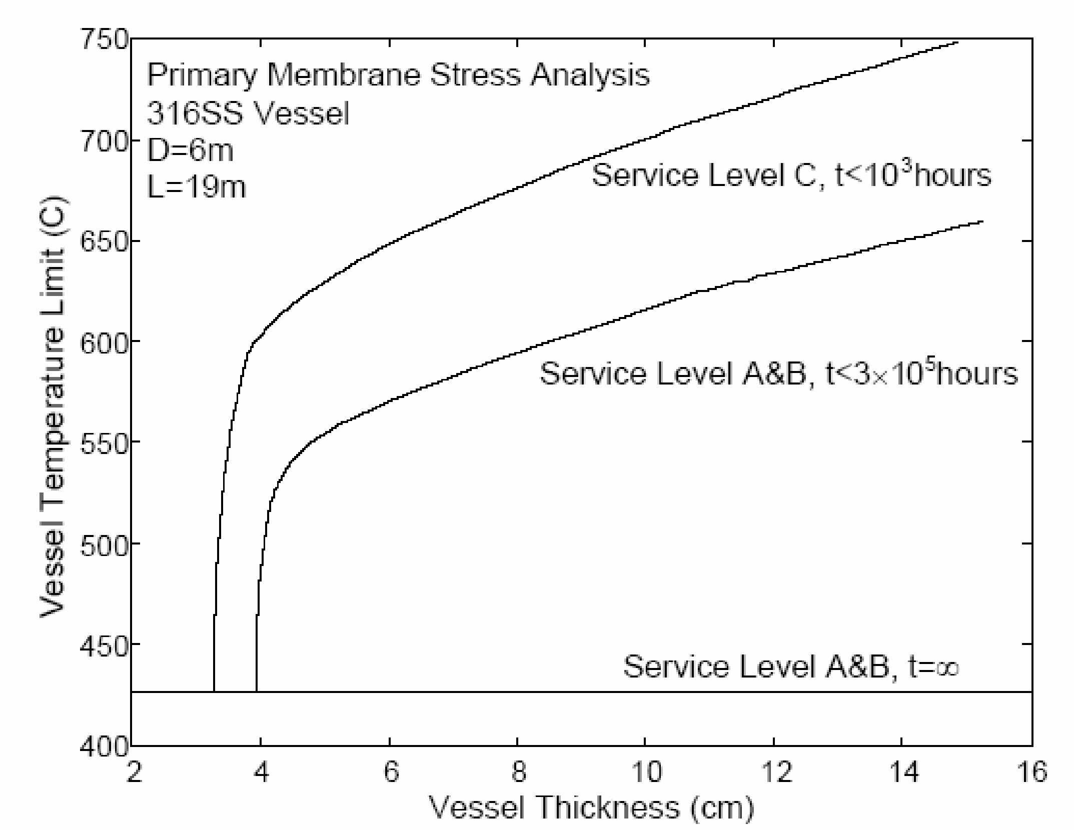
PEACER-300 Primary System





Thermal Limits of Guard Vessel

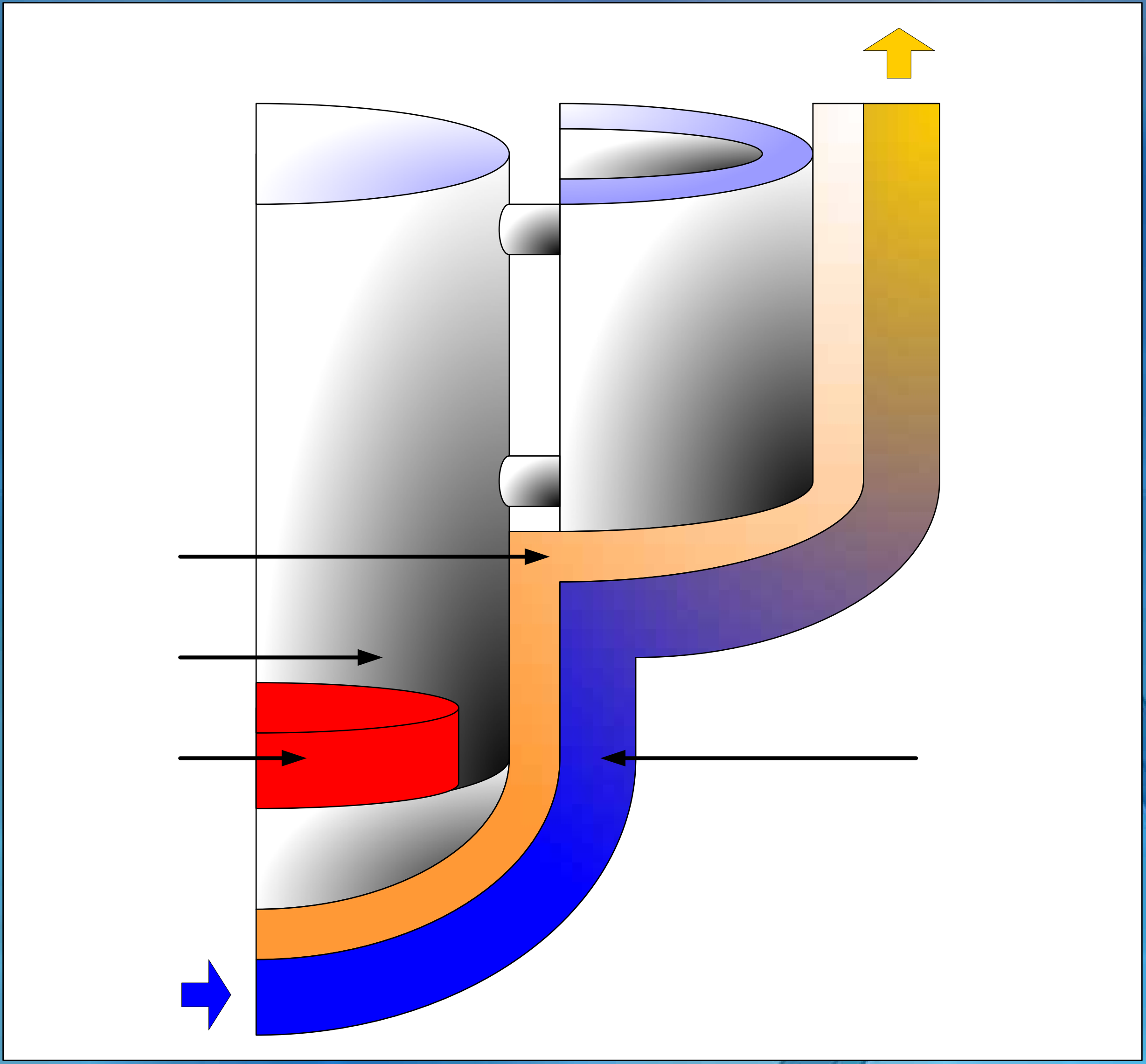




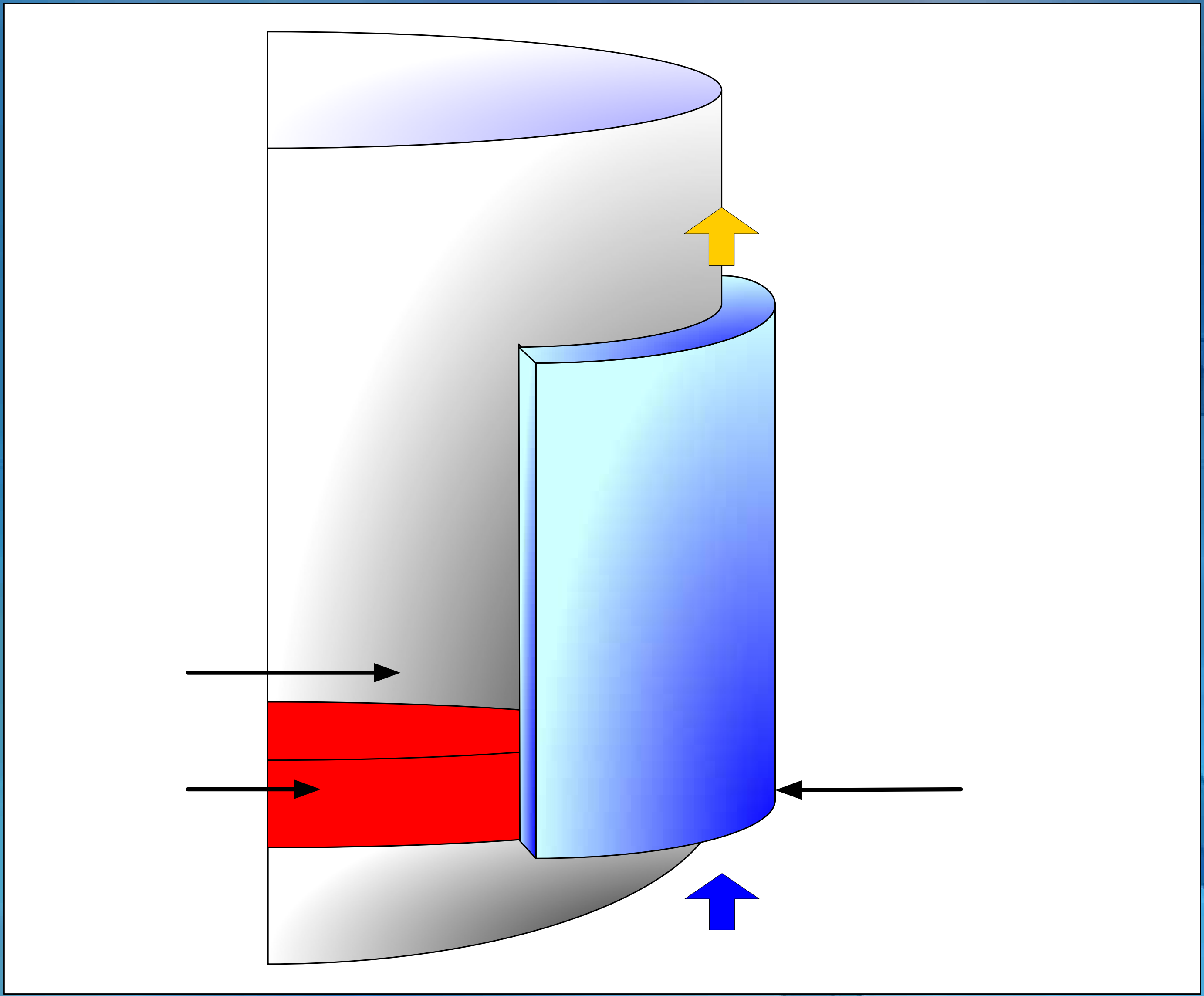
The ASME Code

The ASME Boiler and Pressure Vessel Code Section III, Division 1, Section NH (Class 1 Component in Elevated Temperature Service)

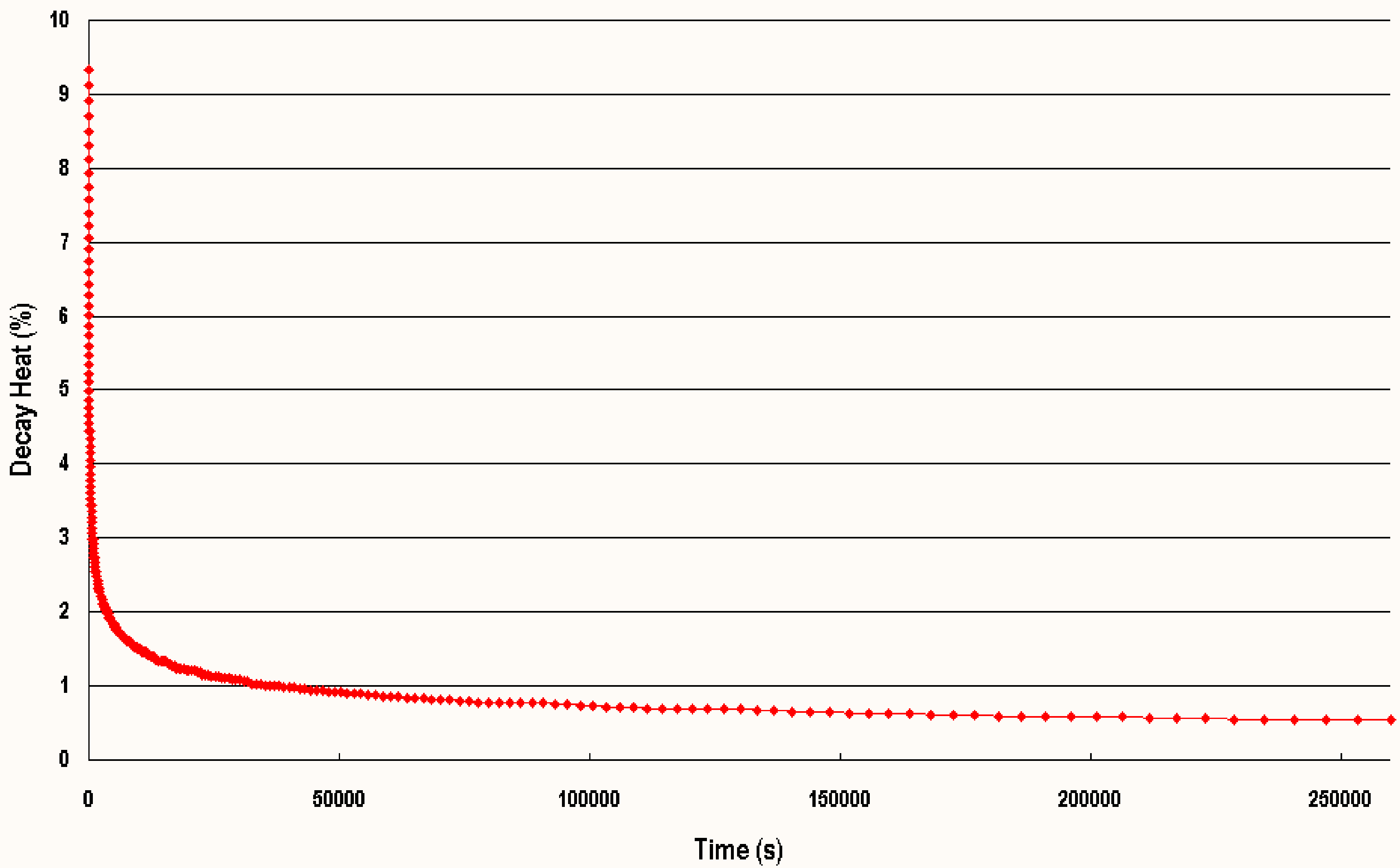
Air Cooling System Layout



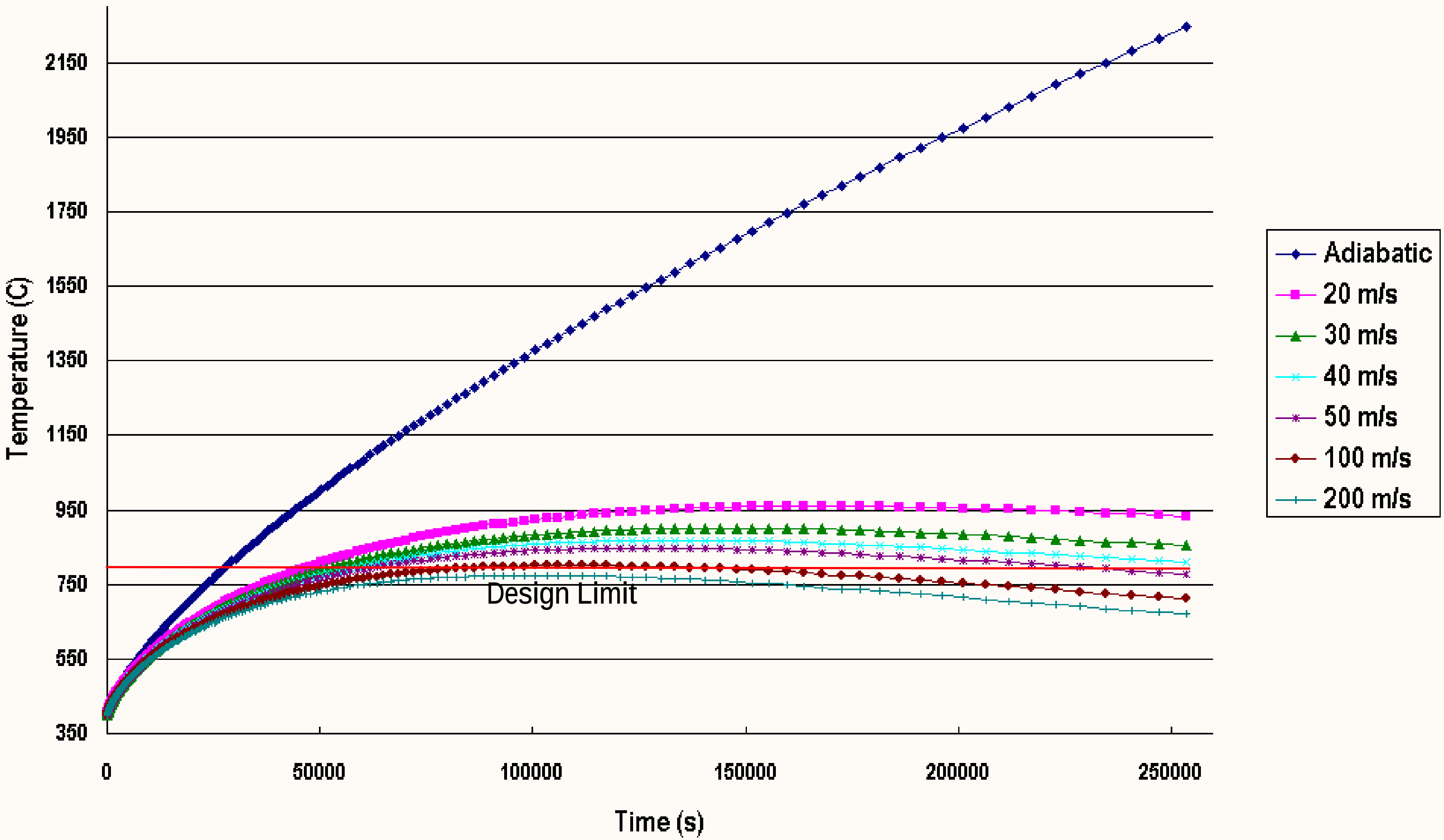
Water Pad System Layout



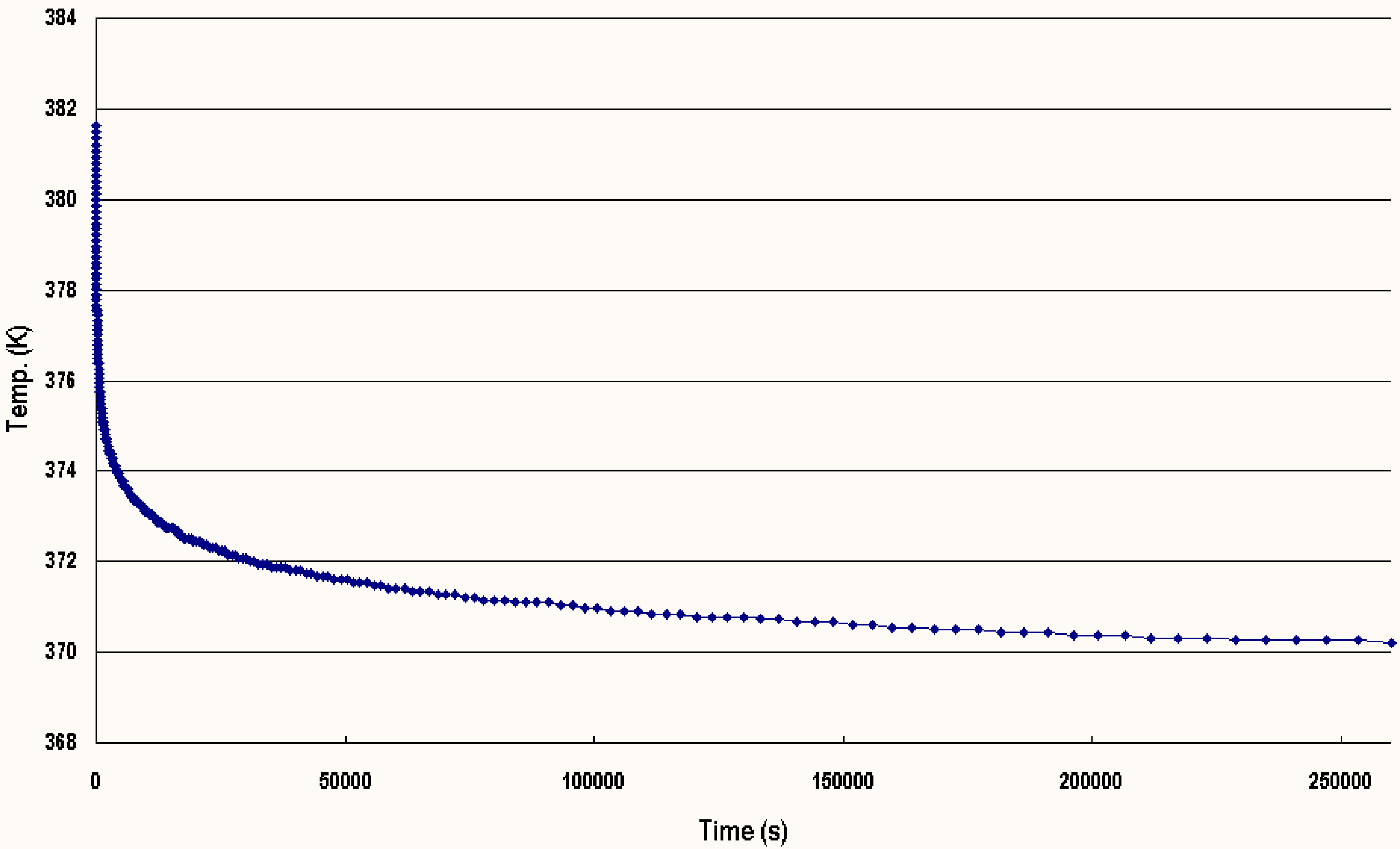
Decay Heat Transient



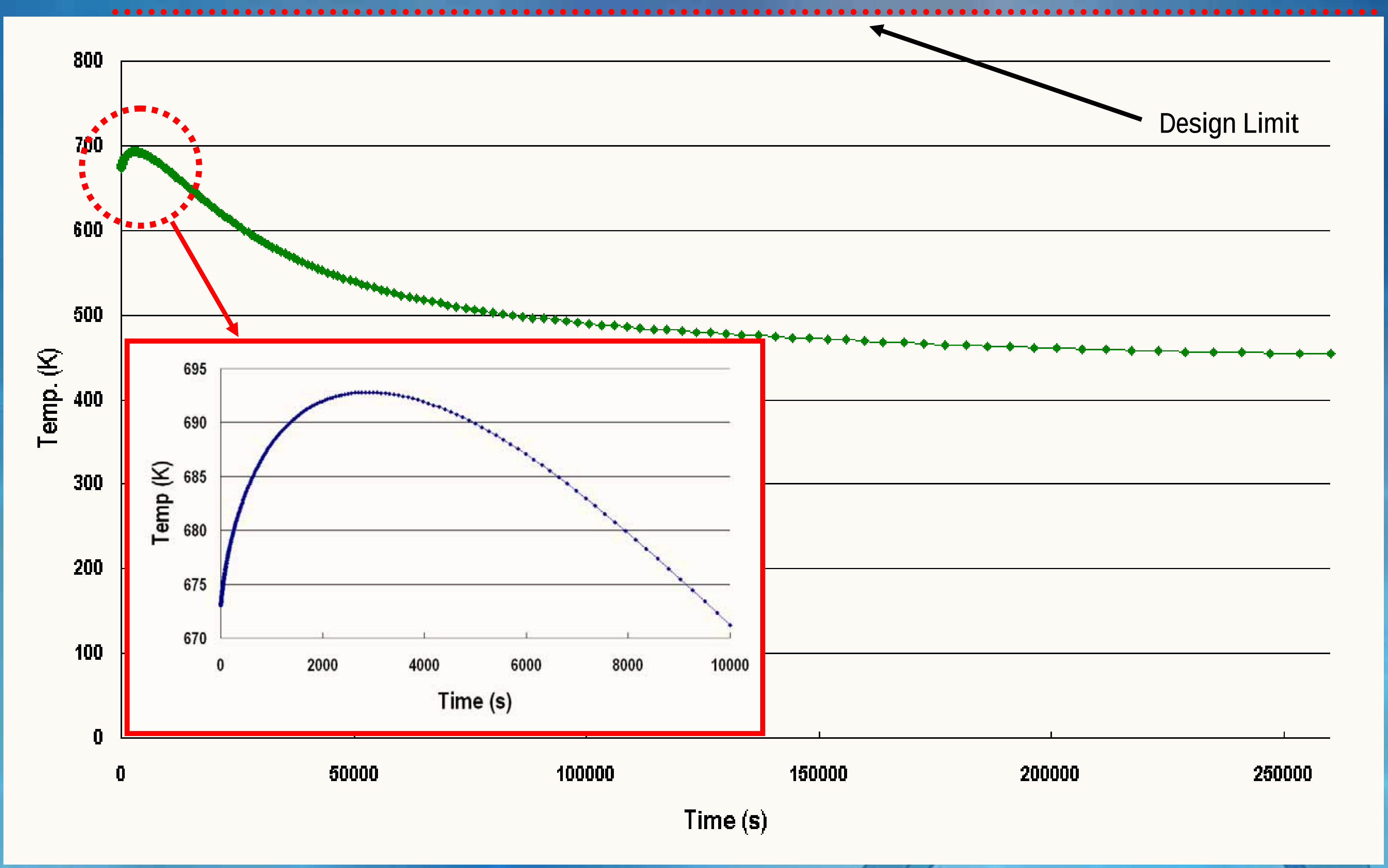
Air Cooling System Efficiency



Reactor Vessel Outer Temperature

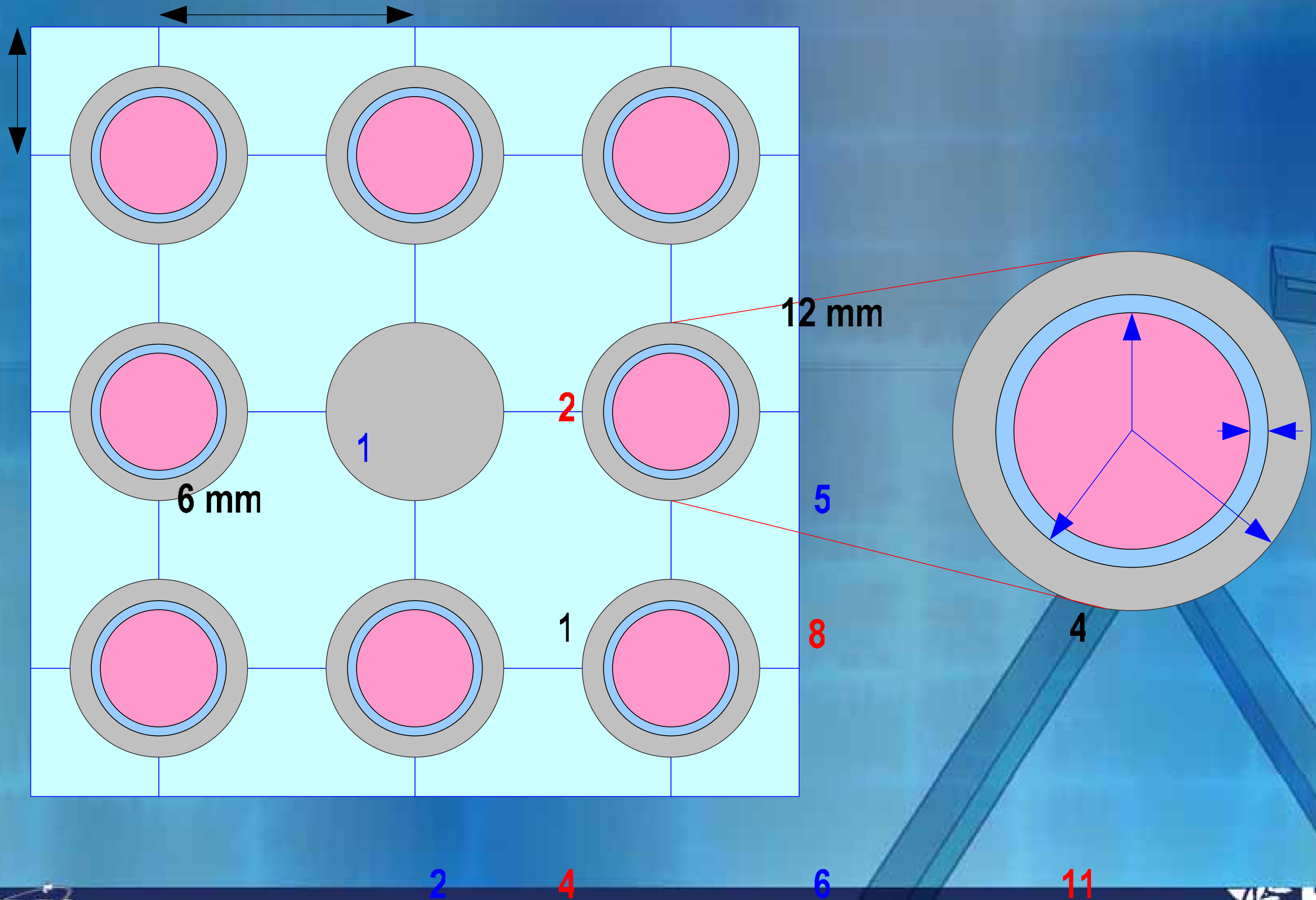


Reactor Vessel Inner Temperature

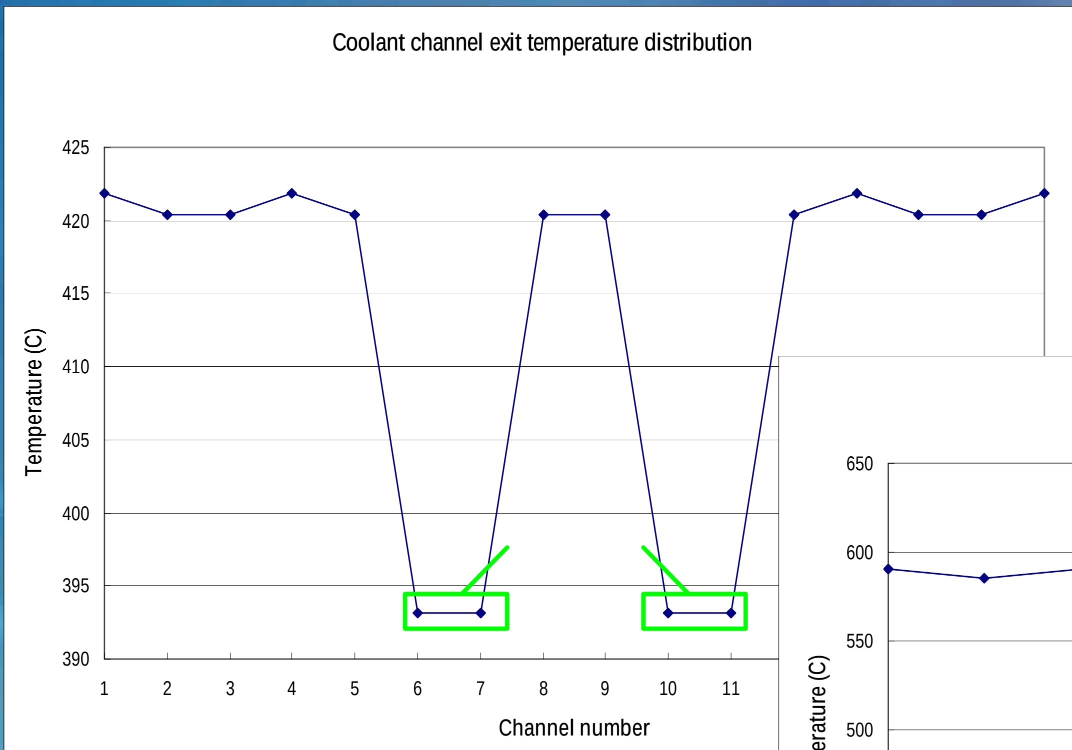


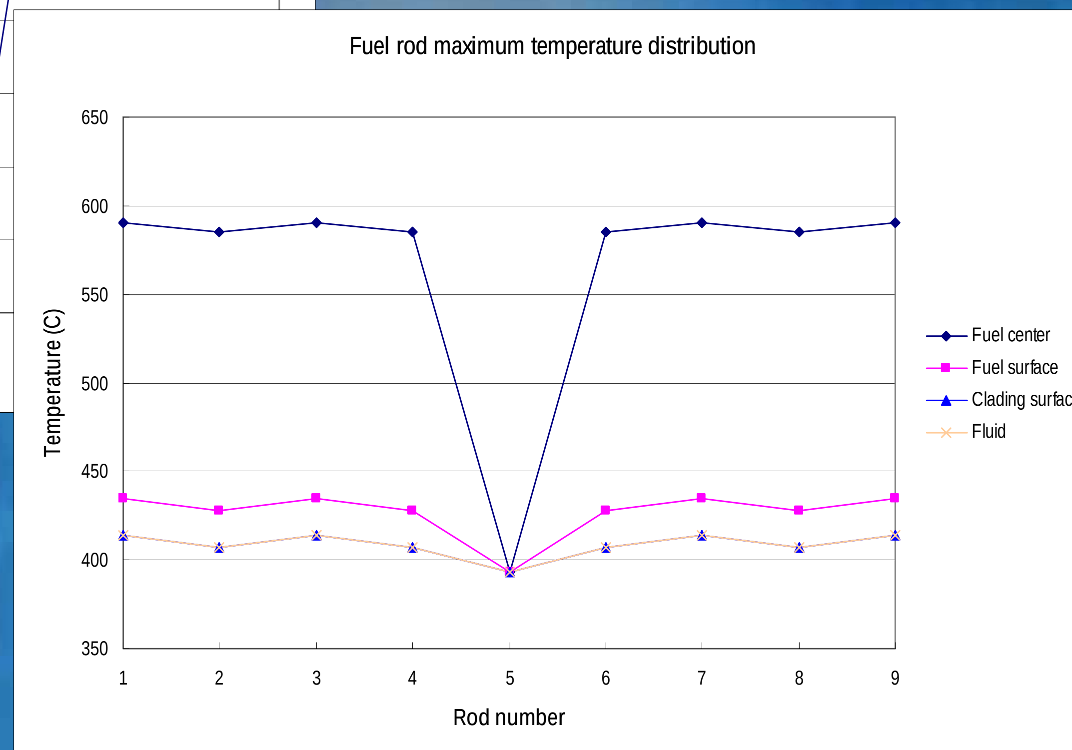
Subchannel Analysis

Region of Interest (3x3)



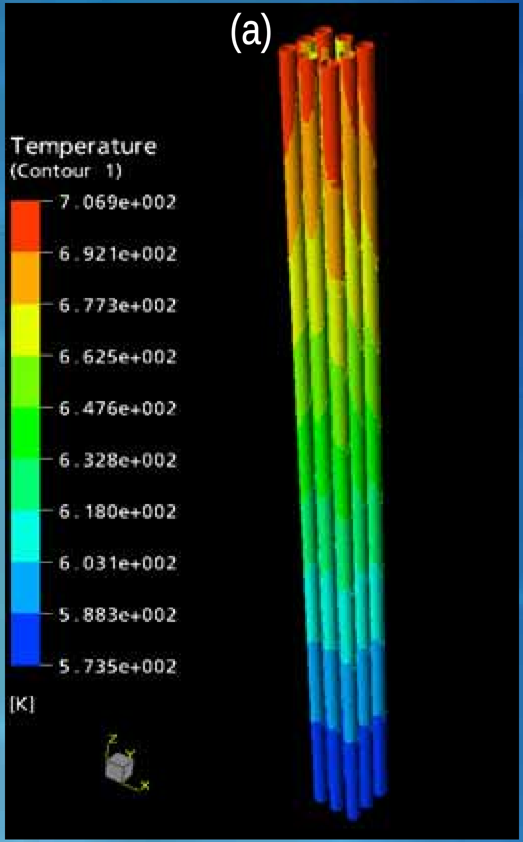
MATRA Calculational Results (3x3)

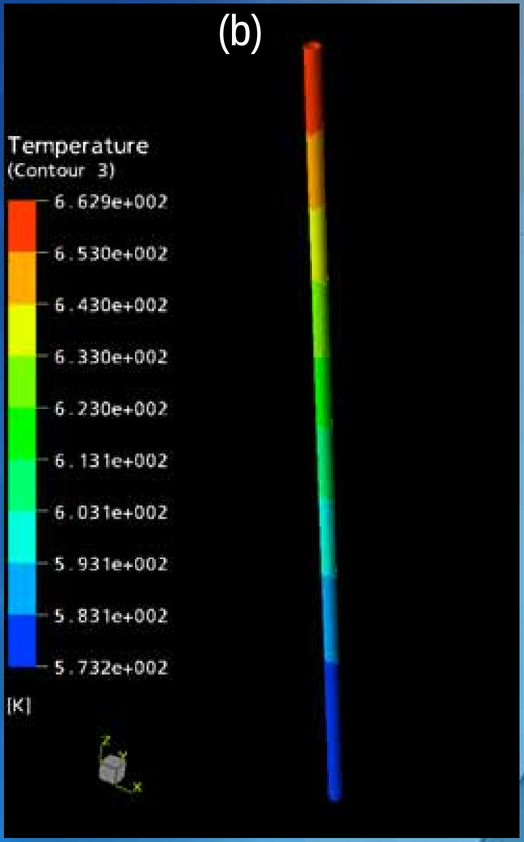


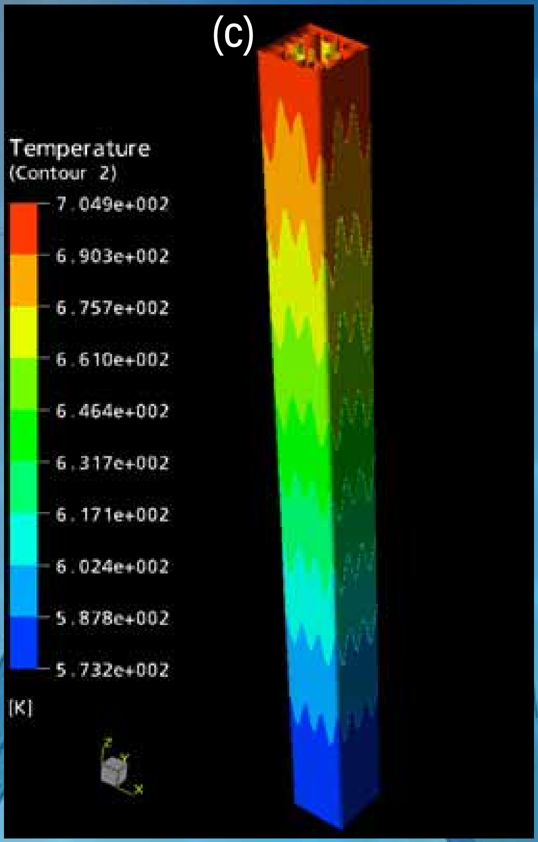


CFX Numerical Results (3x3)

- Coolant temperature on fuel rod surface and at boundary
  - (a) Coolant temperature on fuel rod surface
  - (b) Coolant temperature on a skeleton surface
  - (c) Coolant temperature at symmetry boundary

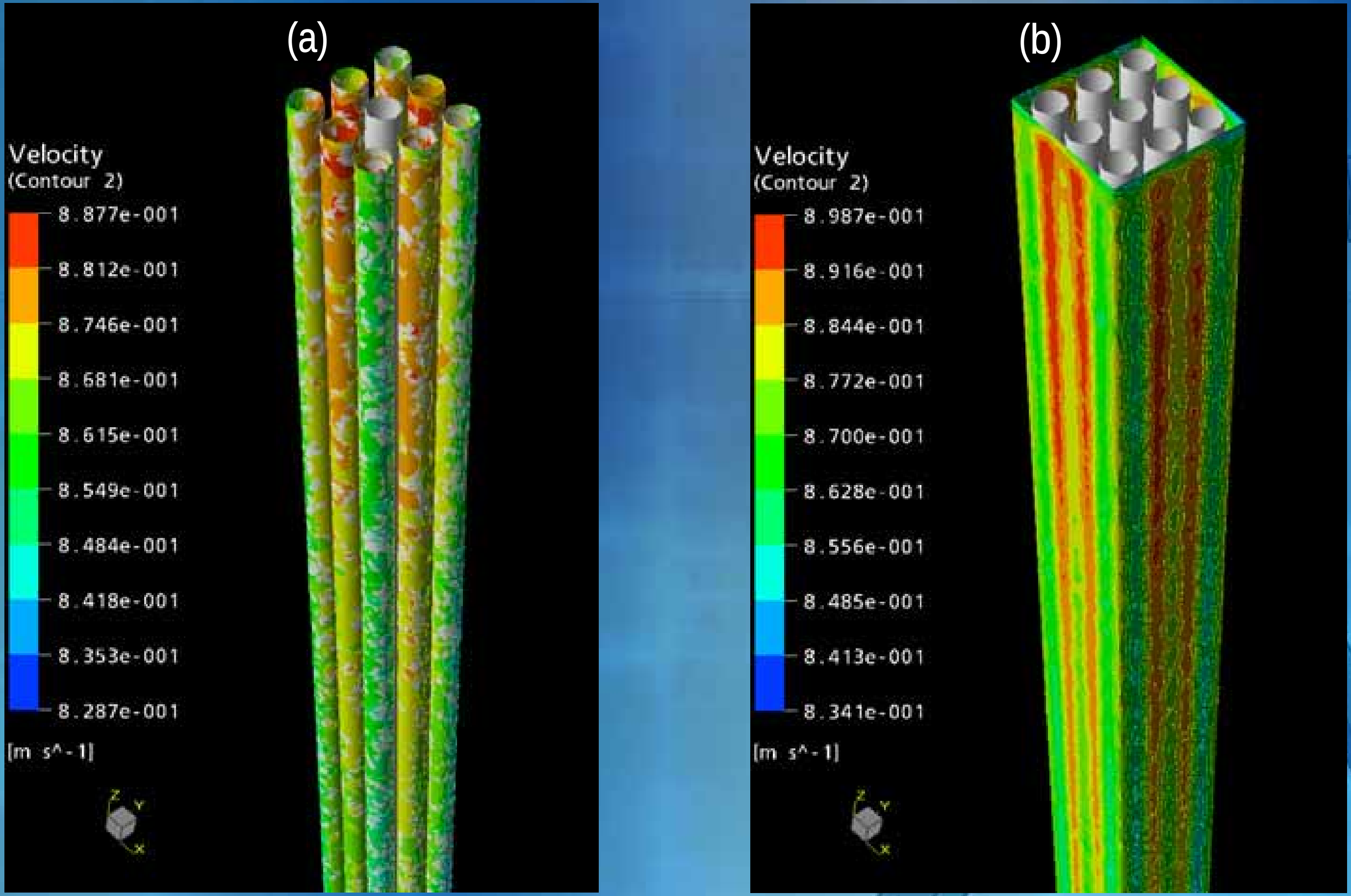






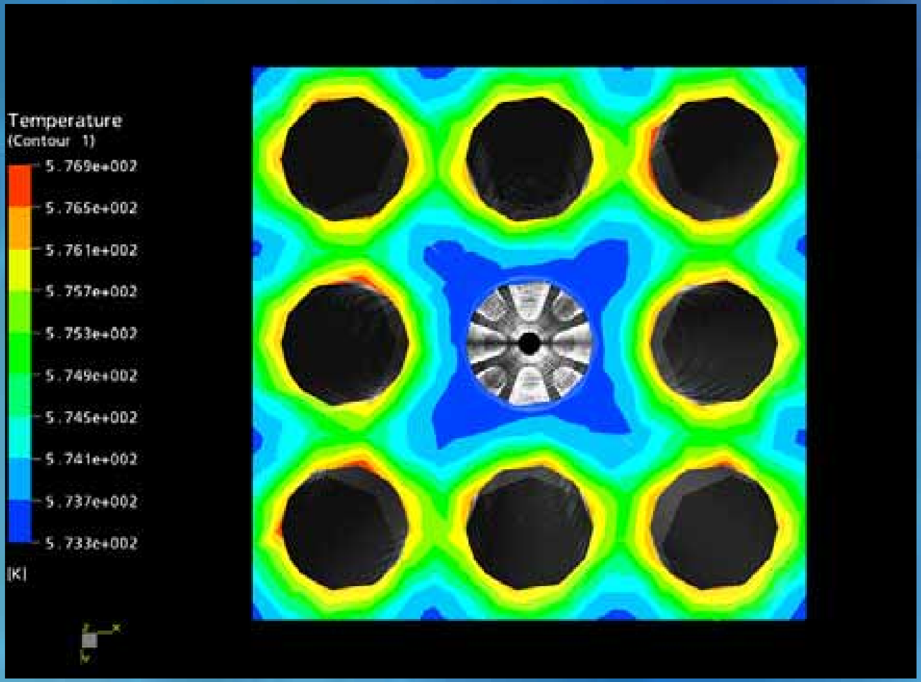
CFX Numerical Results (3x3)

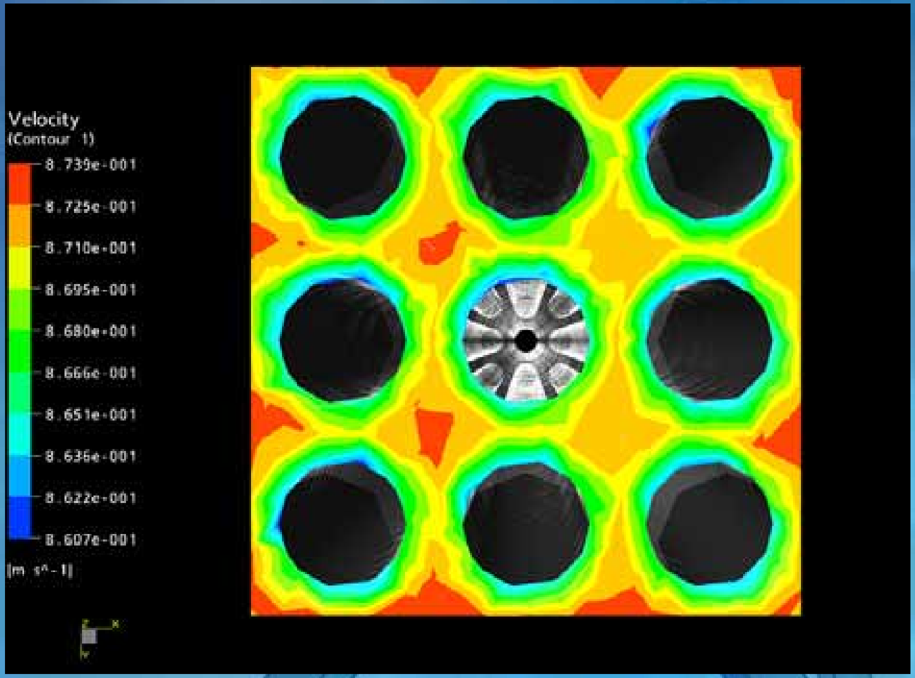
- Coolant velocity on fuel rod surface and at boundary
  - (a) Axial velocity distribution on fuel rod surface
  - (b) Axial velocity distribution at symmetry boundary



CFX Numerical Results (3x3)

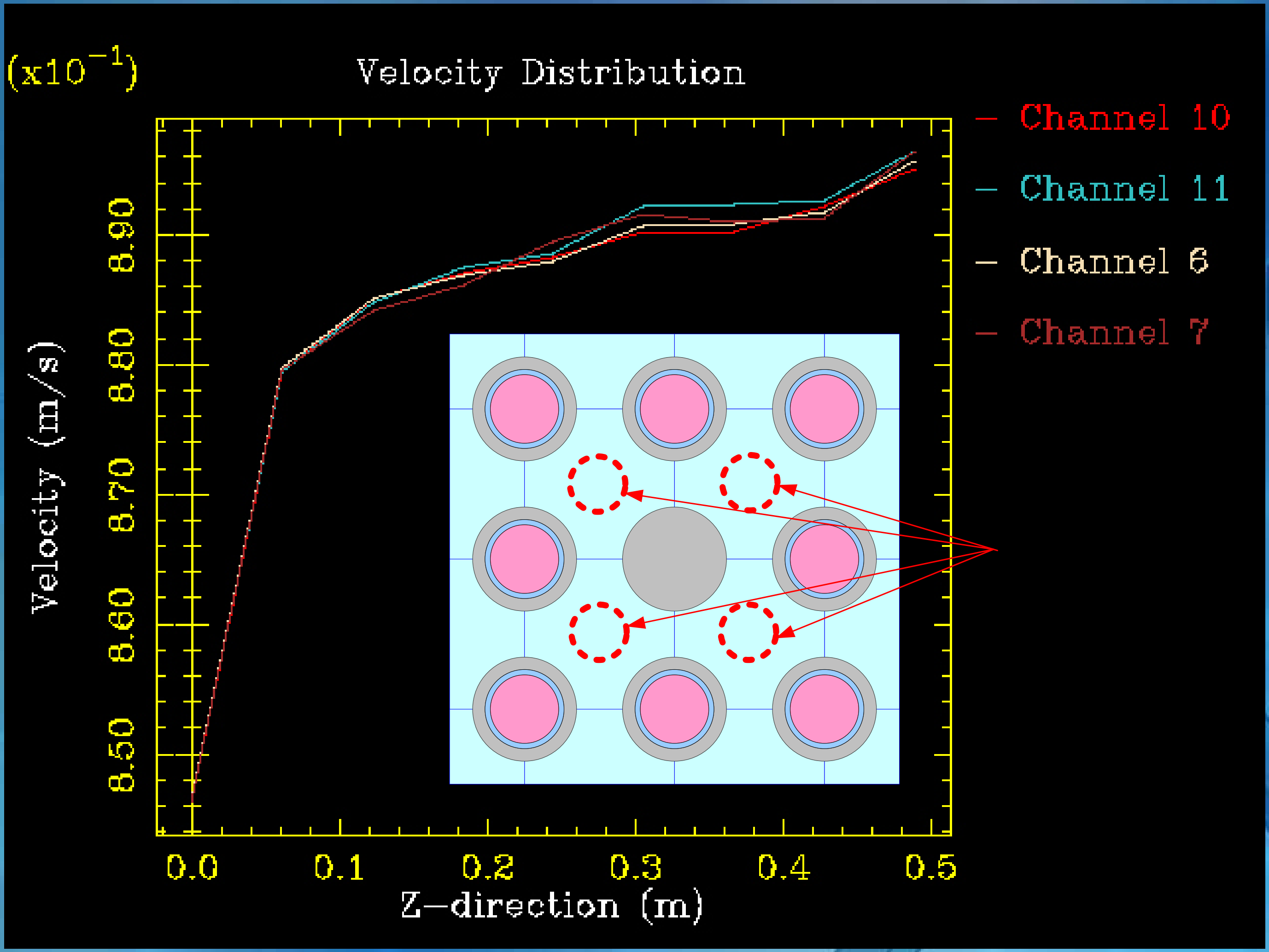
- Temperature and velocity distributions in a horizontal section at z = 0m (inlet)
  - Similar temperature and velocity profiles on each fuel rod except skeleton





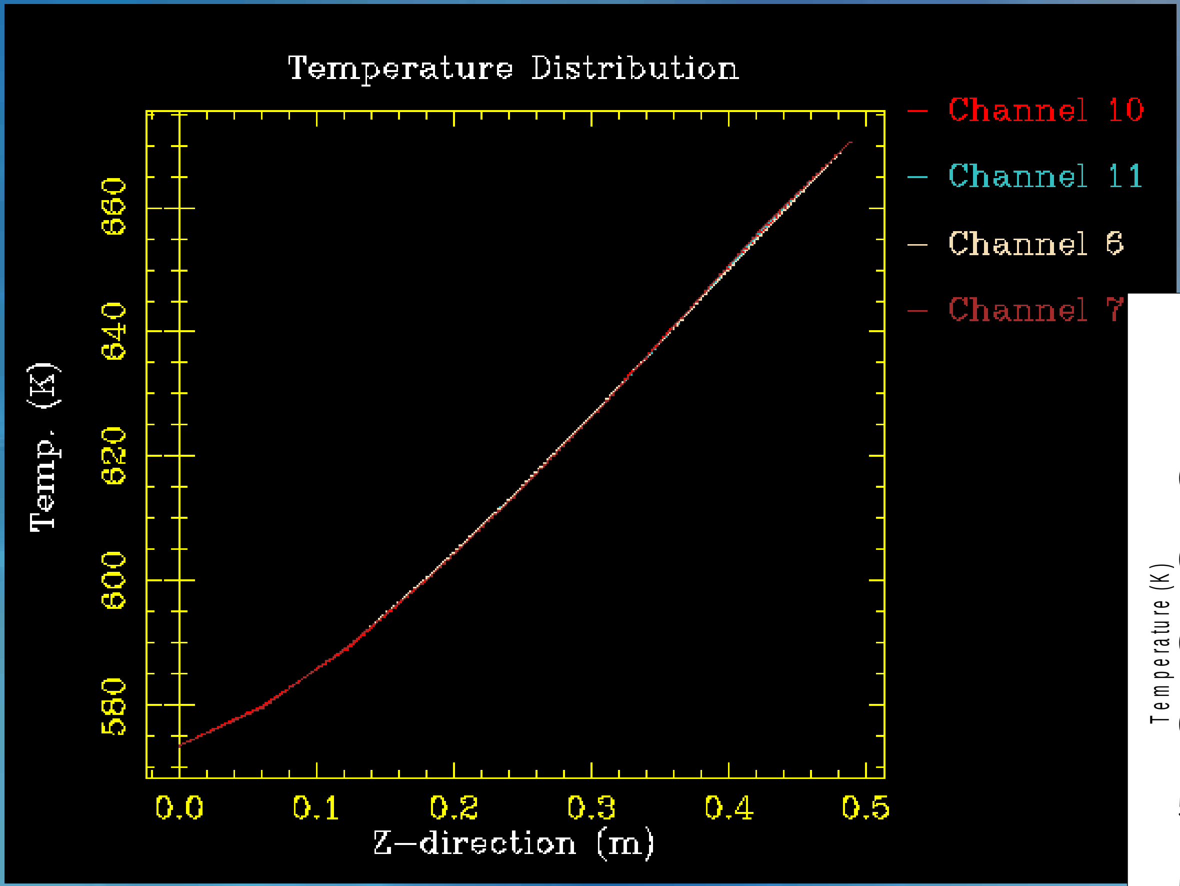
CFX Numerical Results (3x3)

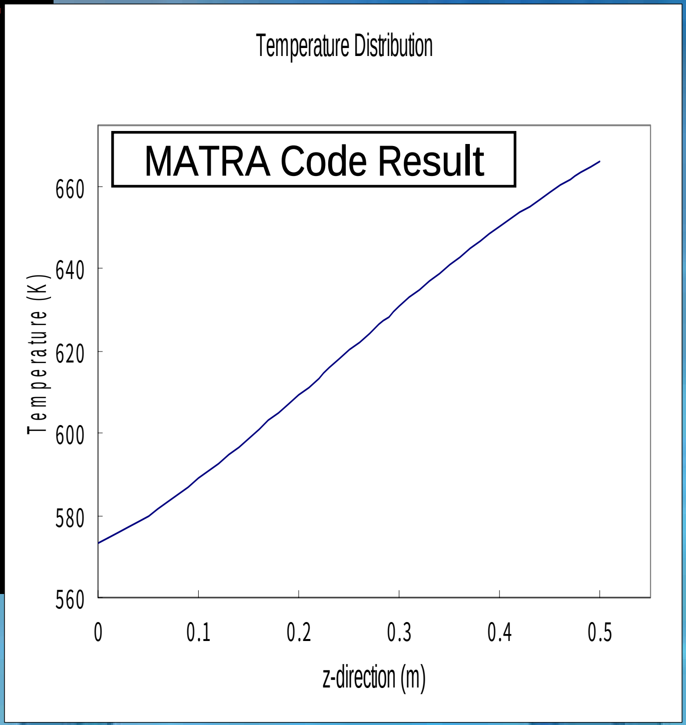
- Axial velocity distribution at center of subchannel



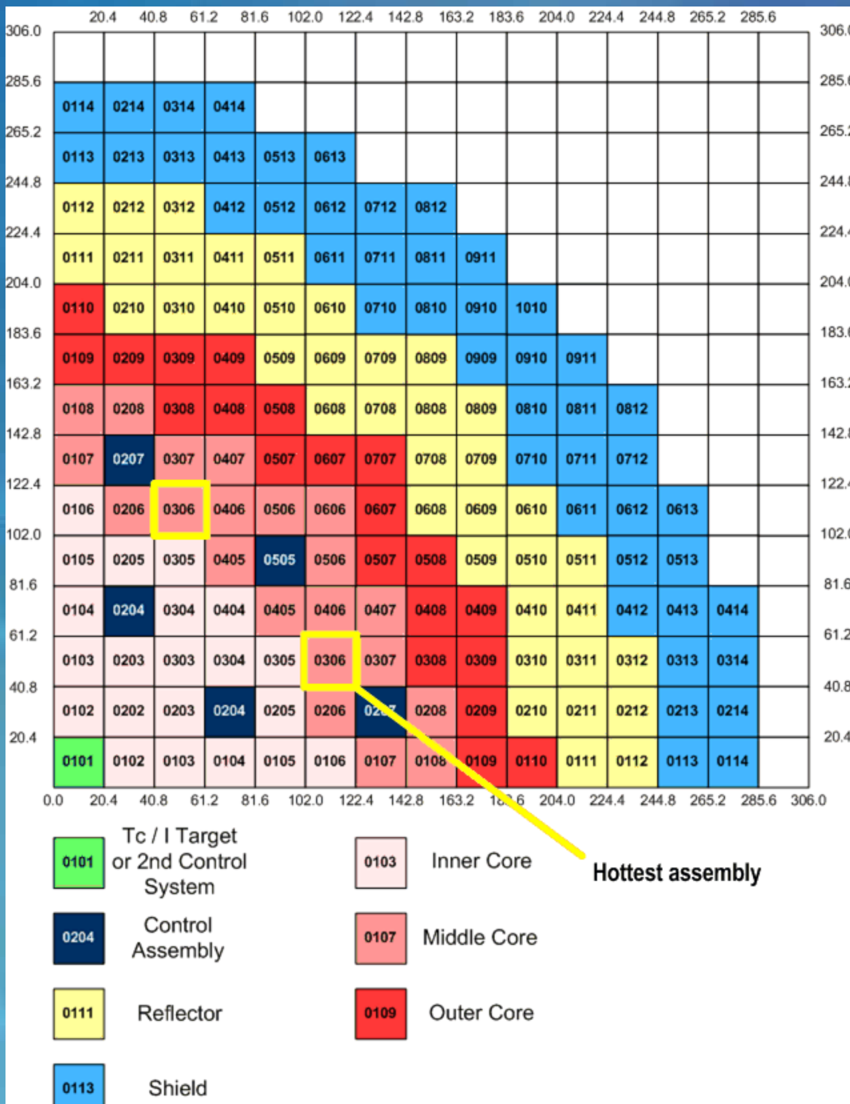
CFX Numerical Results (3x3)

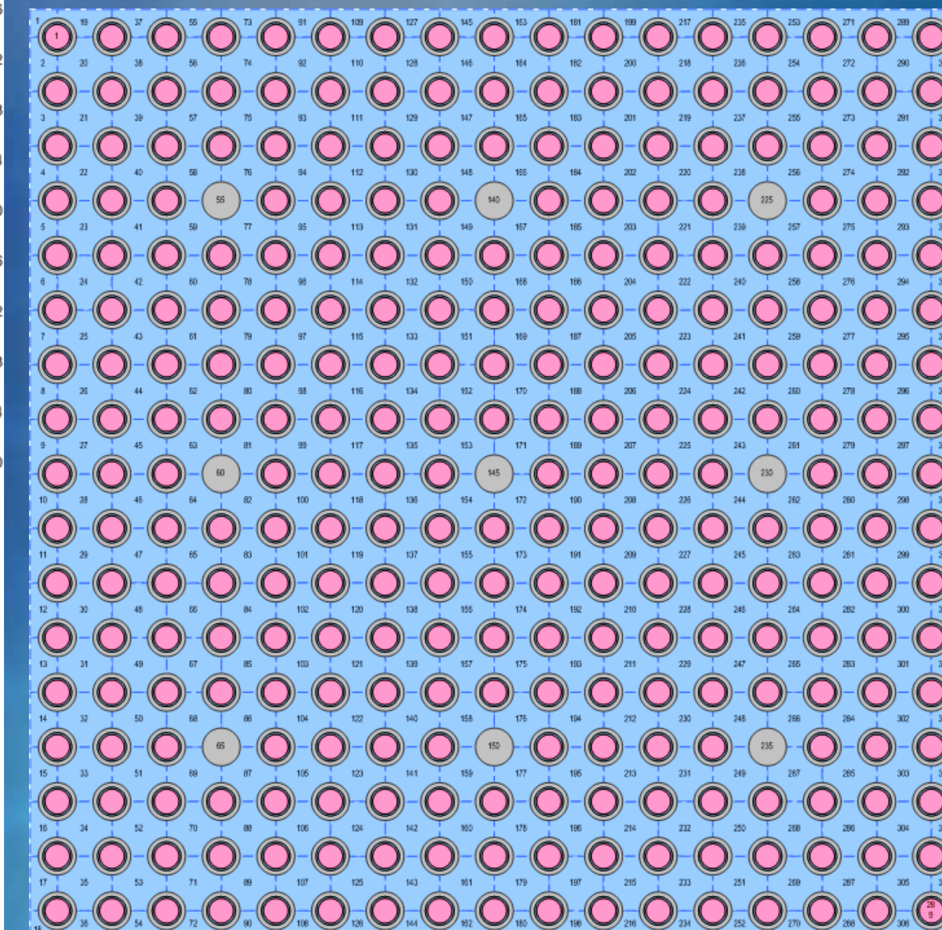
- Axial temperature distribution at center of subchannel





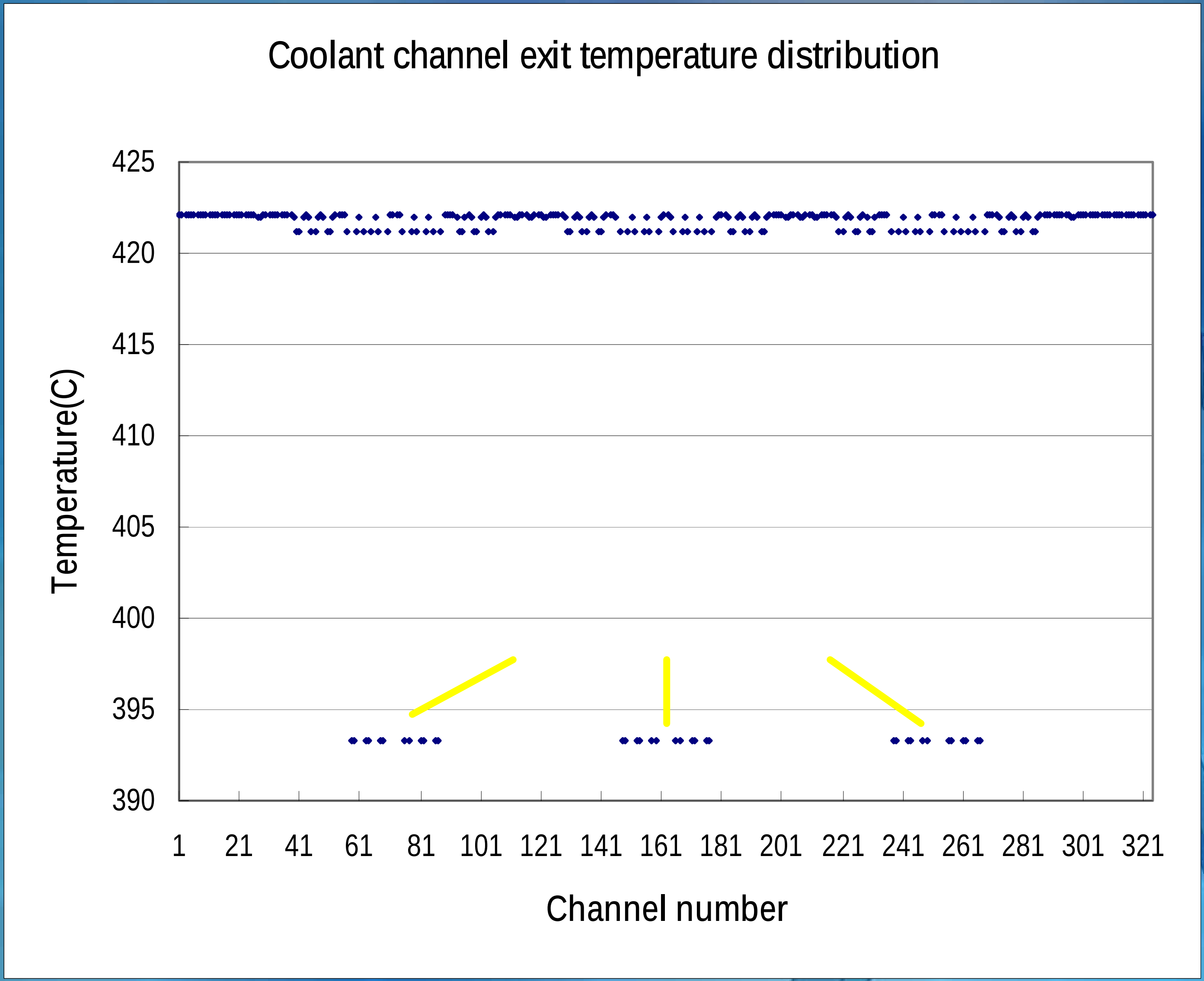
Region of Interest (17x17)



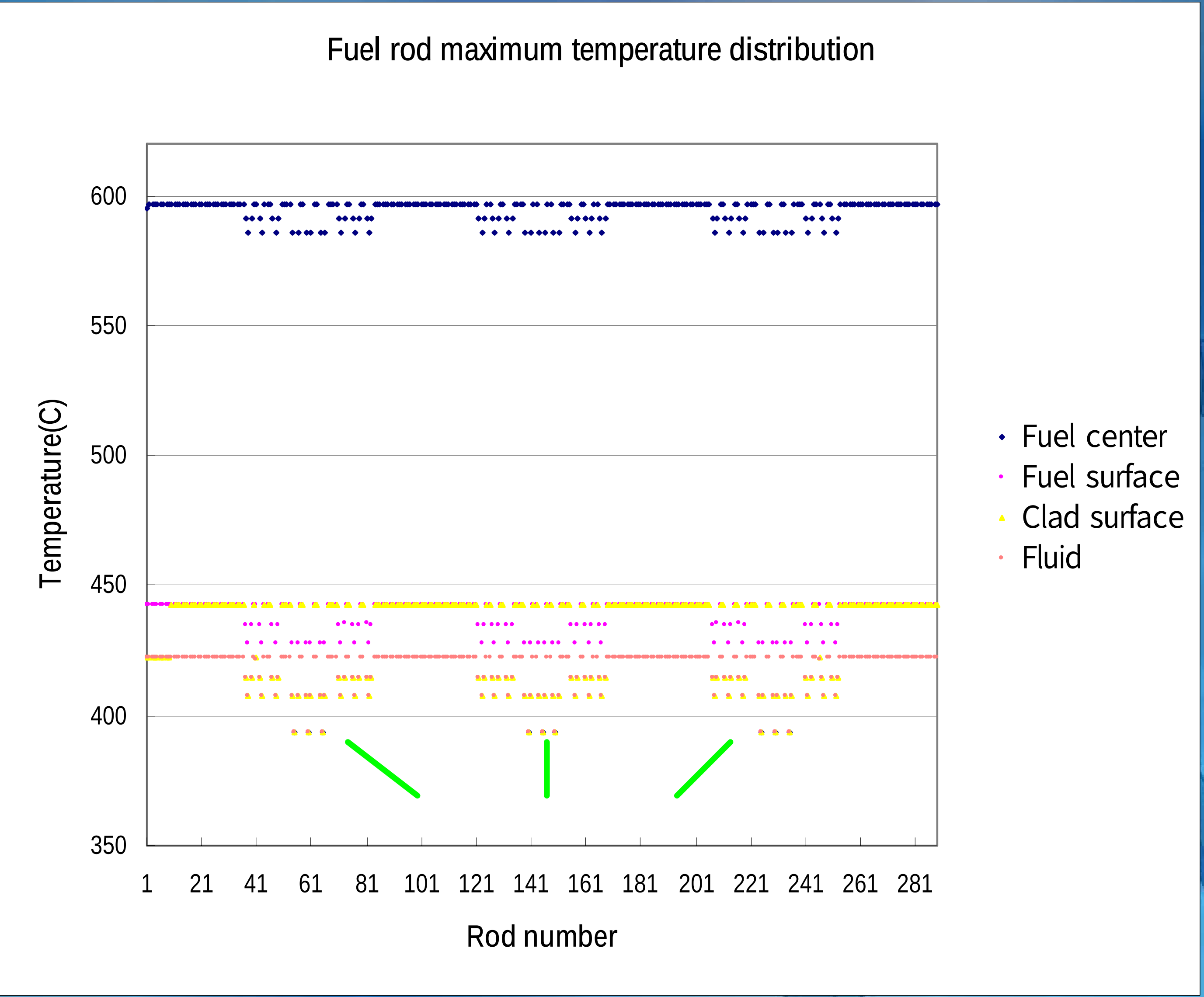


17x17 Full Assembly

MATRA Calculational Results (17x17)

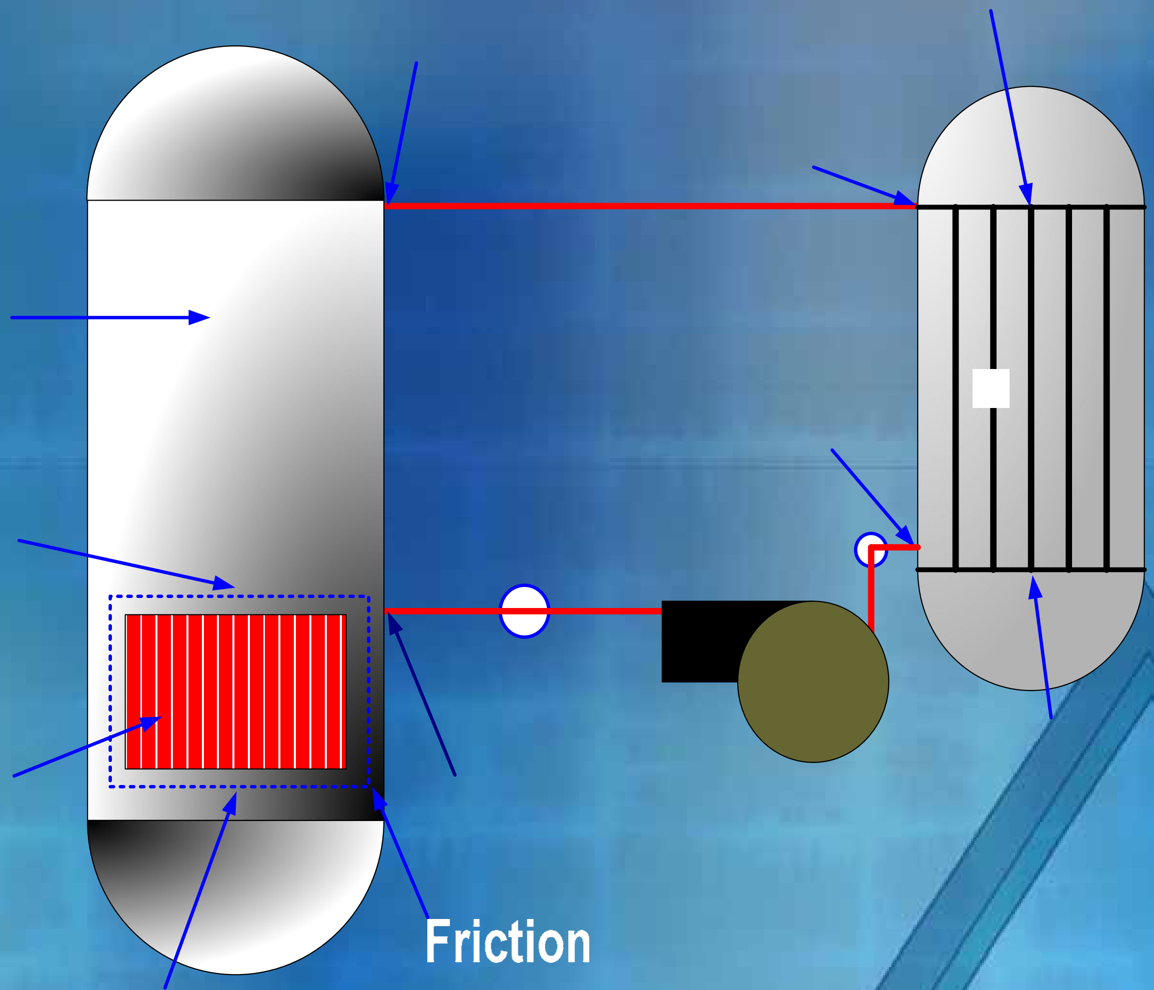


MATRA Calculation Results (17x17)

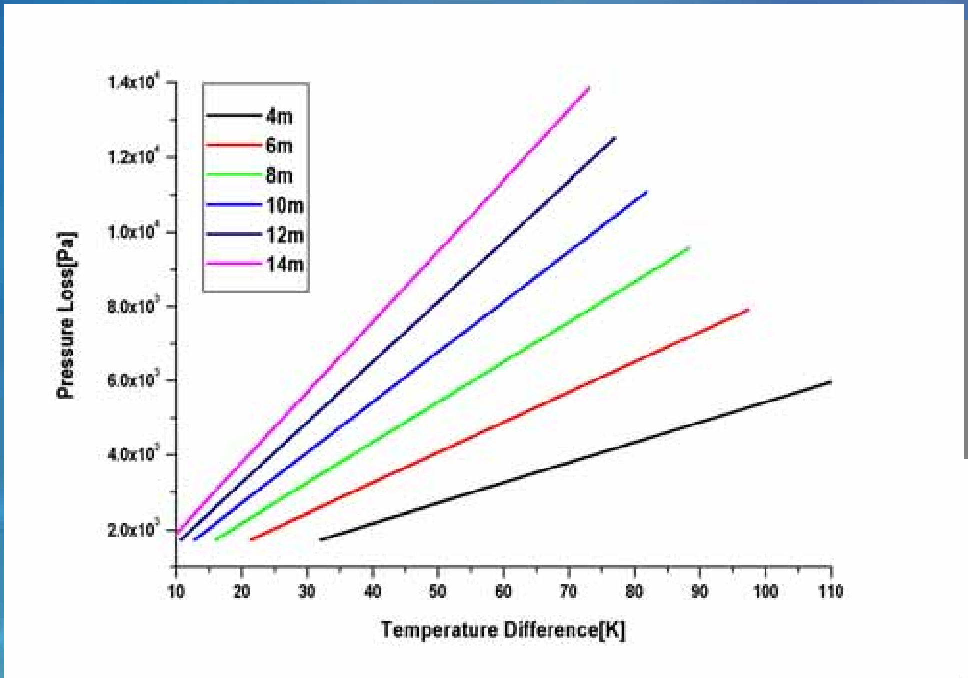


Scaling Analysis

PEACER Primary System

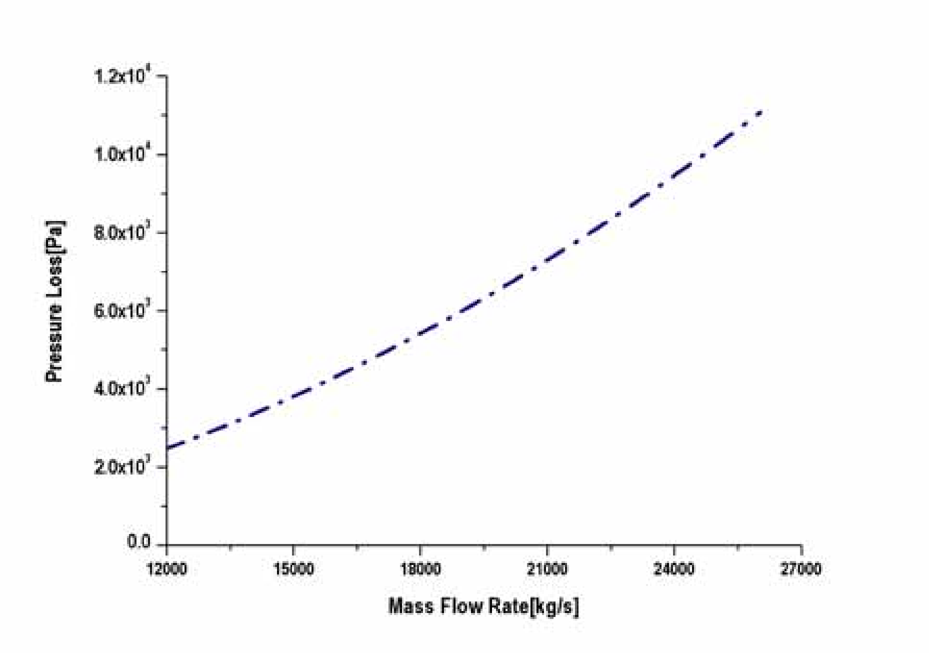


Pressure Loss in PEACER

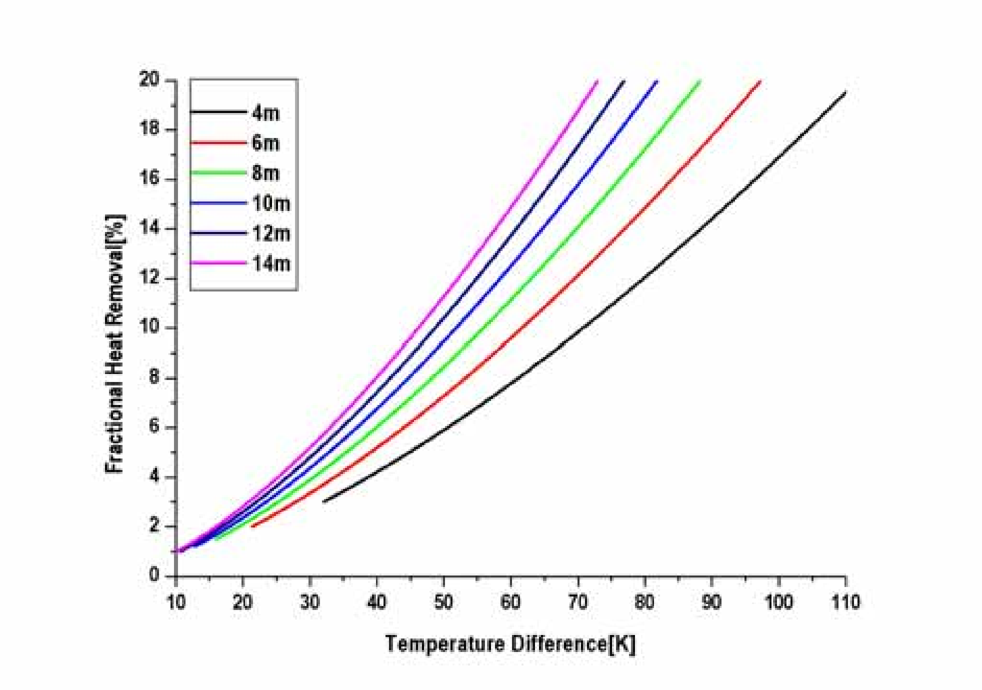


Pressure Loss According to Thermal Center Difference

Pressure Loss According to Mass Flow Rate

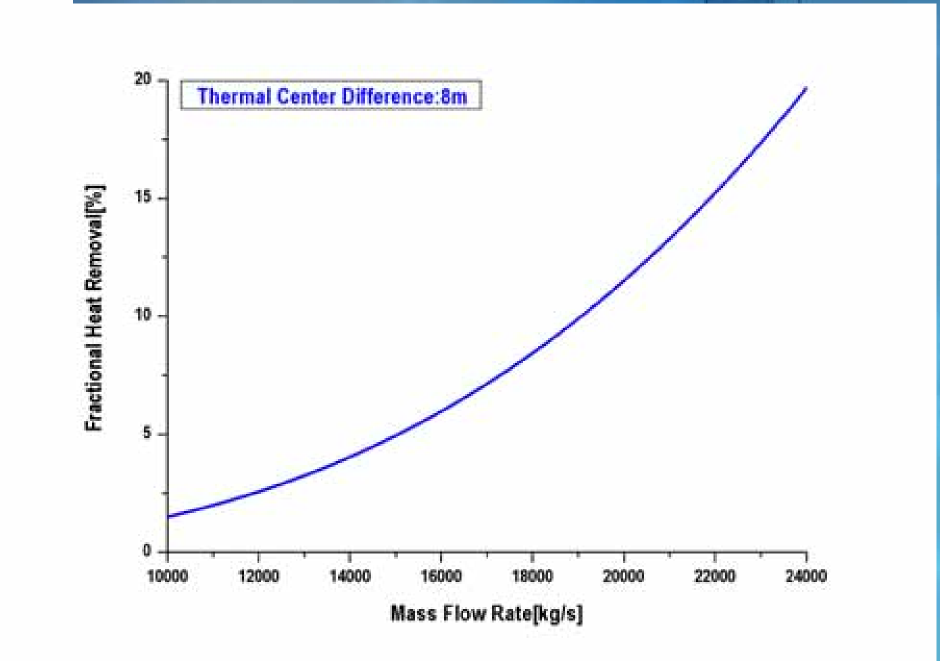


Natural Circulation Capacity of PEACER



Heat Removal According to Thermal Center Difference

Heat Removal According to Mass Flow Rate



Scaling Analysis

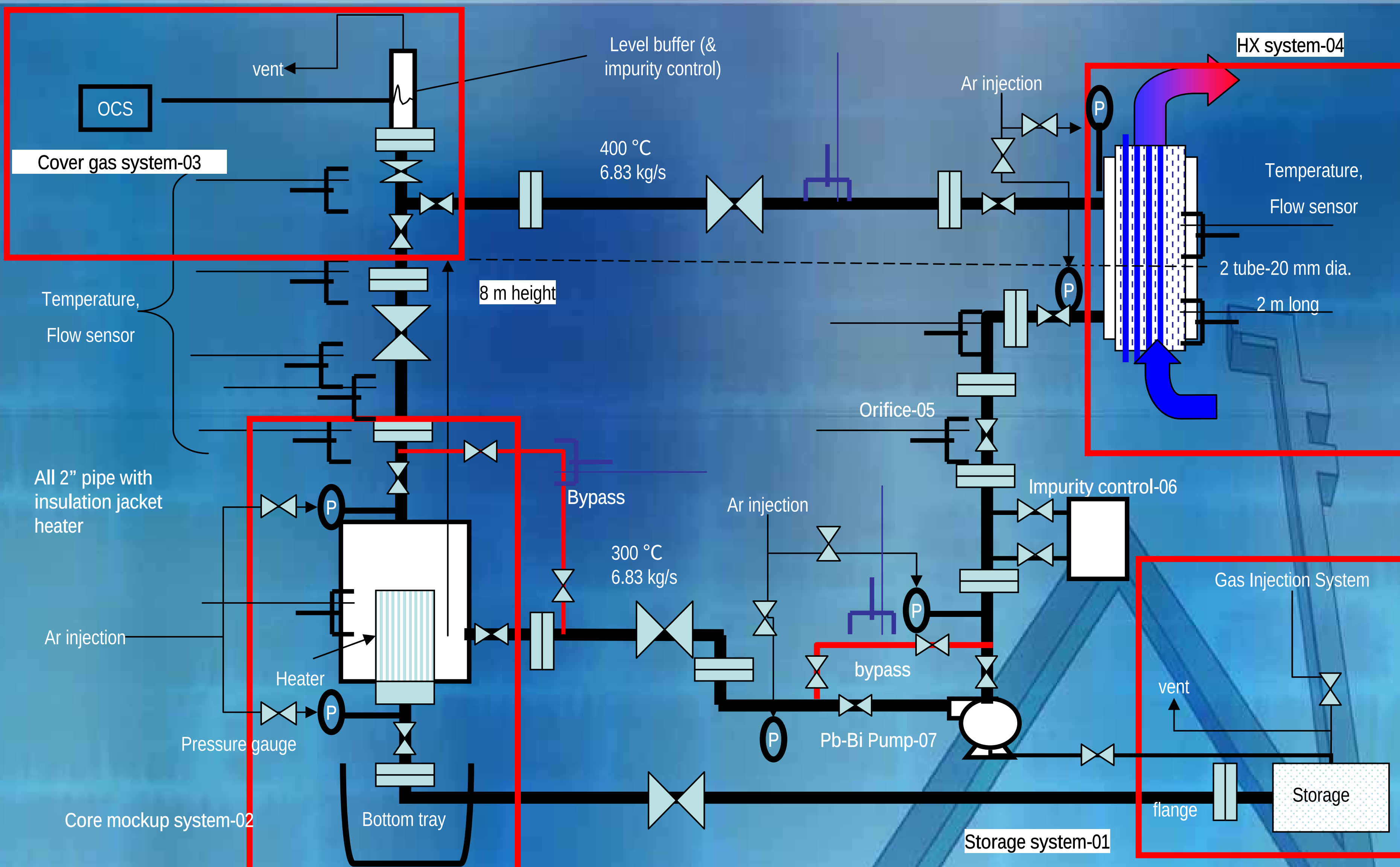
Continuity	Momentum Equation
$U_i = \frac{a_o}{a_i} U_r$	$\rho \frac{dU_r}{dt} \sum_i \frac{a_o}{a_i} l_i = \beta g \rho \Delta T l_h - \rho \frac{U_r^2}{2} \sum_i \left(f \frac{l}{d} + K \right)_i \left(\frac{a_o}{a_i} \right)^2$

$$Ri = \frac{g \beta \Delta L \Delta T}{U^2}$$

$$F = \sum \left(f \frac{L}{D} + K \right)$$

Design Parameter	PEACER	HELIOS
Richardson Number	14.80	14.80
Friction Number	29.5	7.5
Thermal Center Difference [m]	8	8
Velocity in Core [m/s]	0.199	0.199
ΔT [°C]	55.4	55.4
Thermal Power	156 MW	9.3 kW

HELIOS Primary System P&I D



HELIOS Design

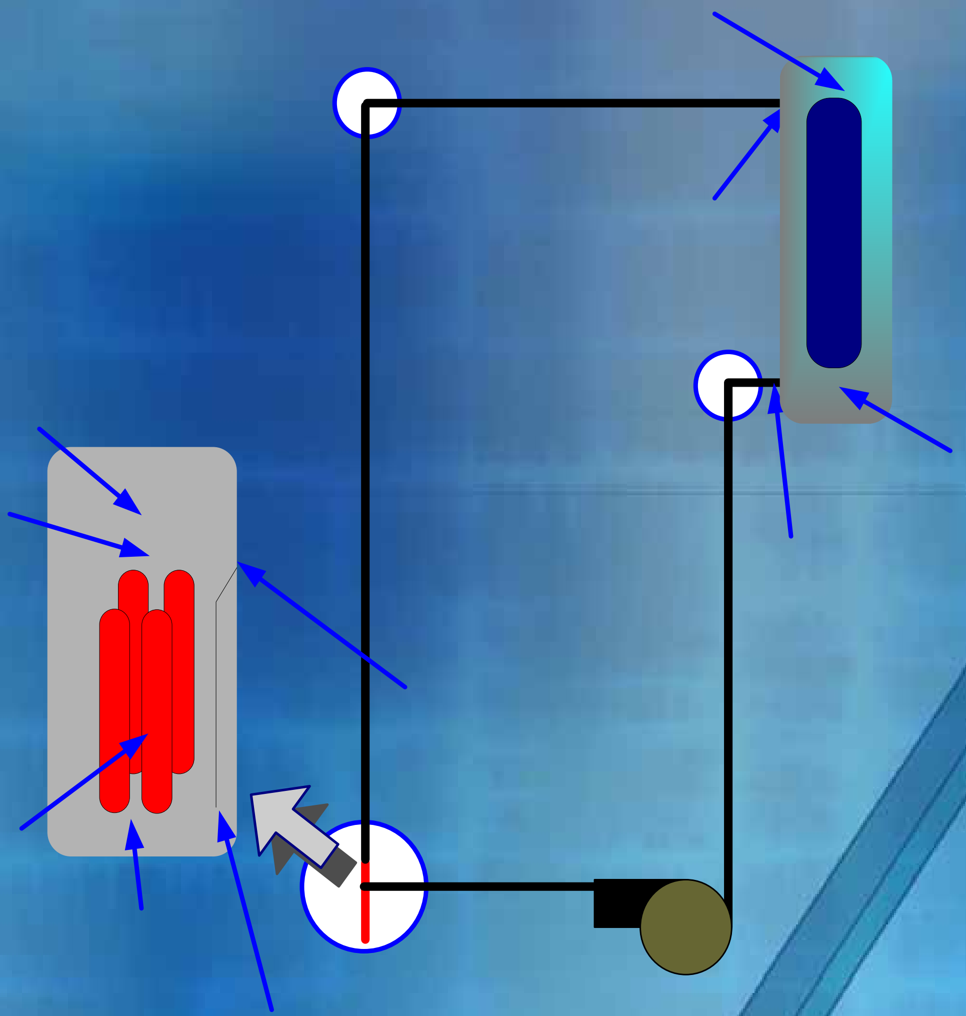
Initial Conditions

Parameter	PEACER	HELIOS
Number of Loops	2	1
Flow Area of Core [m^2]	9.4371	0.0020
Hydraulic Diameter [m]	0.01703	0.0271
Thermal Center Difference [m]	8	8

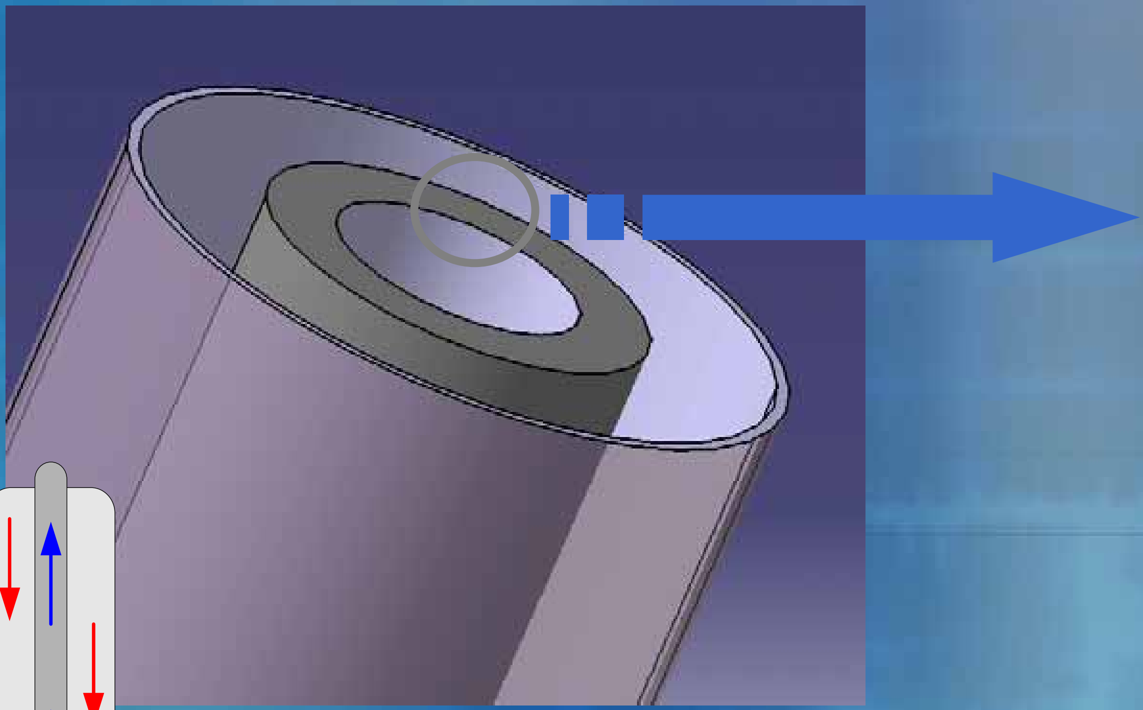
Natural Circulation Results

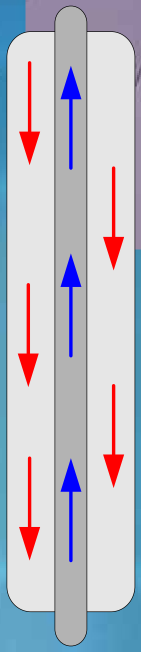
Parameter	Value
Decay Power [MW_{th}]	156
Mass Flow Rate [kg/s]	19,237
Temperature Difference [K]	55.4
Velocity in Core [m/s]	0.199

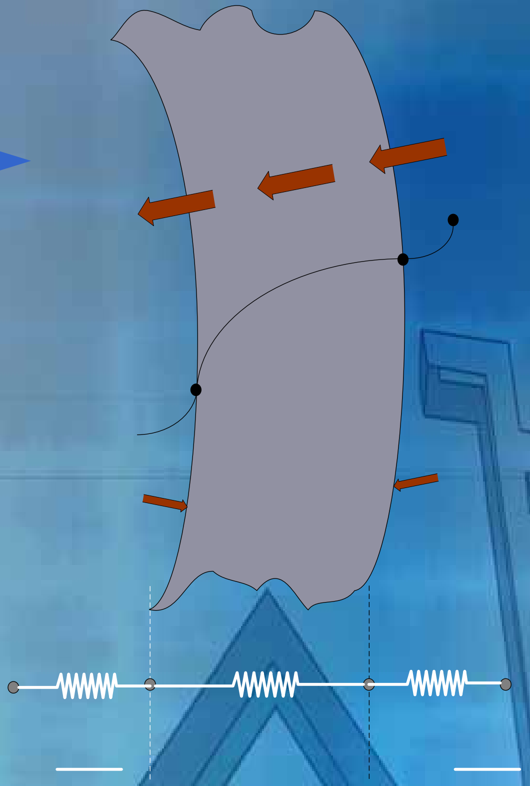
HELIOS Schematic Diagram



Heat Transfer Mechanism







Heat Exchanger Design:

Log-Mean Temperature Difference

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\Delta T_1 / \Delta T_2\right)}$$

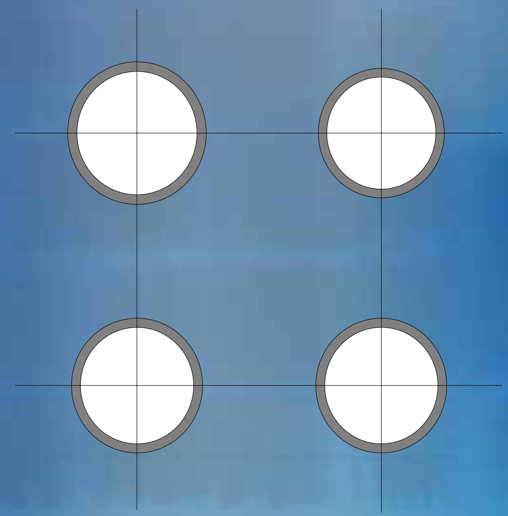
$$\Delta T_1 = \Delta T_{Pb-Bi,in} - \Delta T_{W,out}$$

$$\Delta T_2 = \Delta T_{Pb-Bi,out} - \Delta T_{W,in}$$

Subchannel Analysis

Step 1

General Friction Factor
-Core & SG: Square Lattice

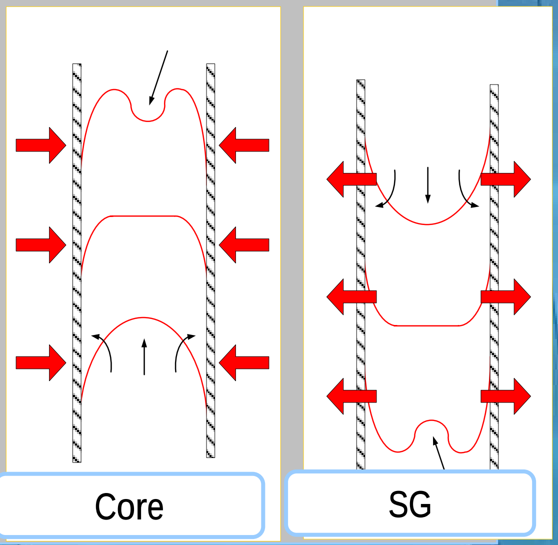


Step 2

Mixed Convectional Friction Factor

Core: Square Lattice
Heated Upward Flow

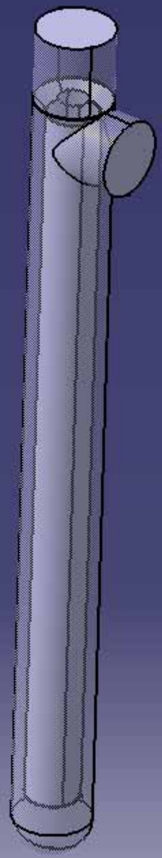
SG: Triangular Lattice
Cooled Downward Flow



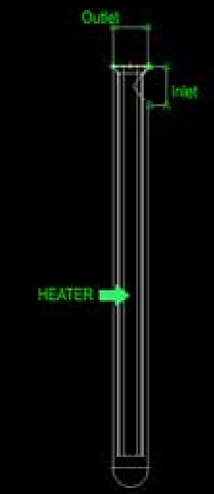
From CAD to CFX

Heating Region

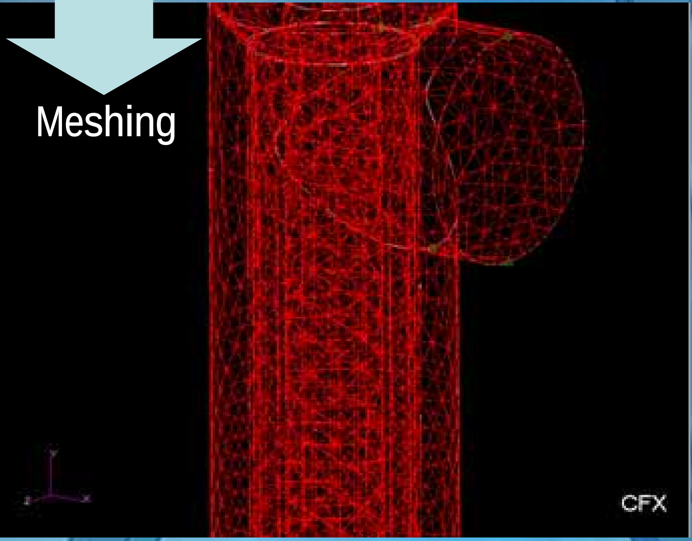
CAD Modeling



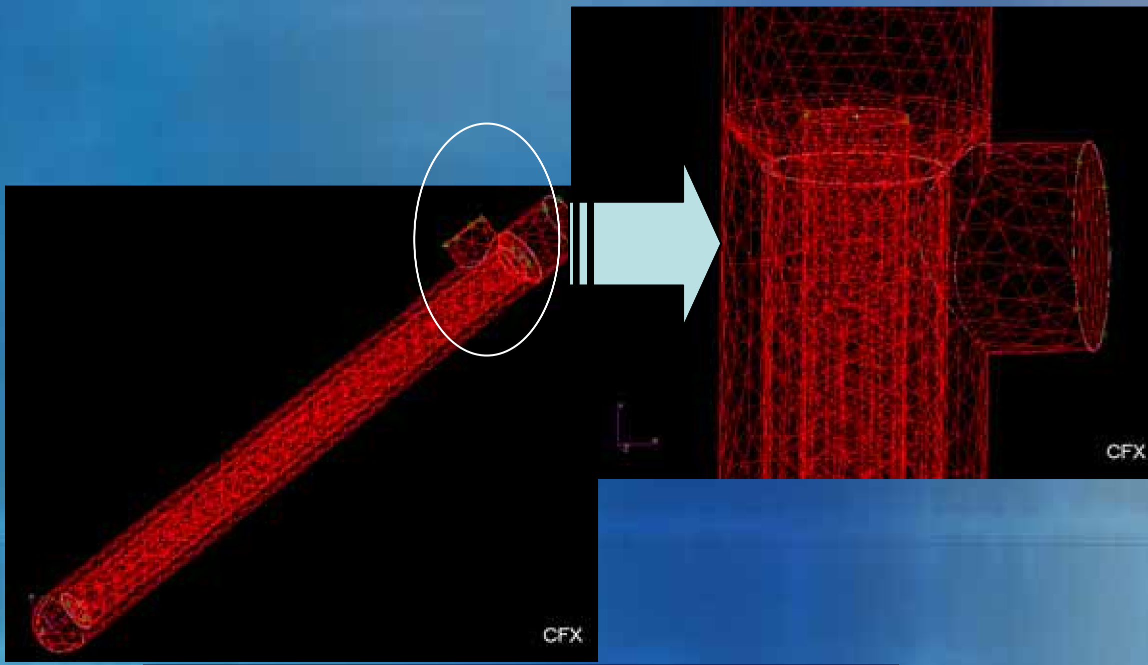
Importing

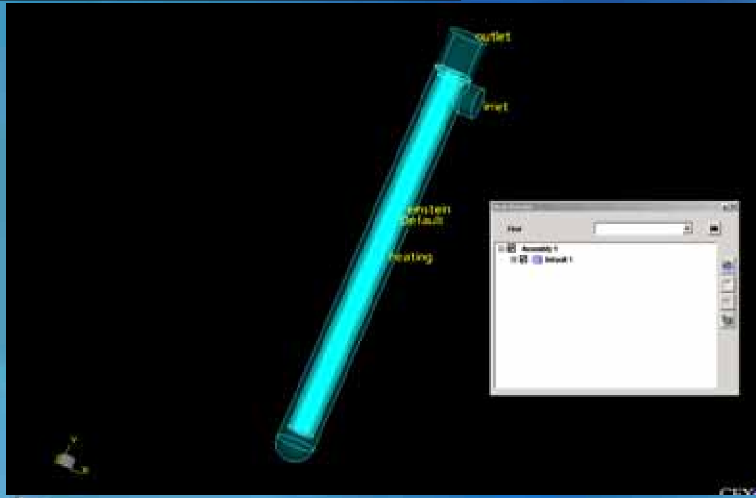


Meshing



Solver Boundary Condition





Inlet Boundary Condition

- Mass Flow Rate: 6.83 kg/s

Outlet Boundary Condition

- Mass Flow Rate: 6.83 kg/s

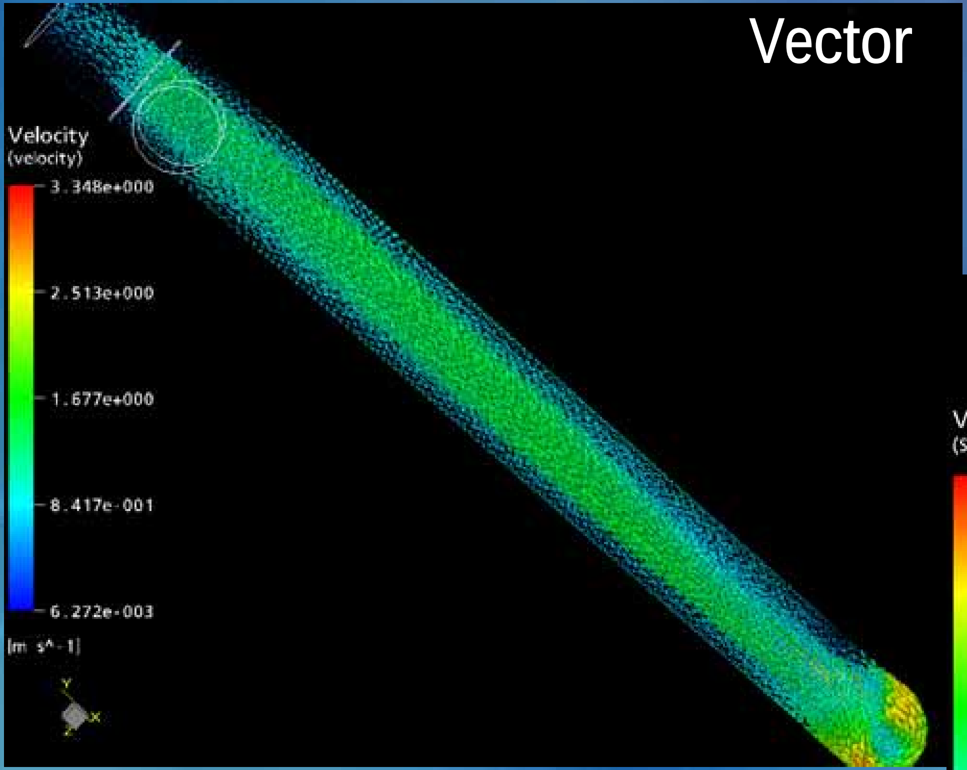
Heating Source

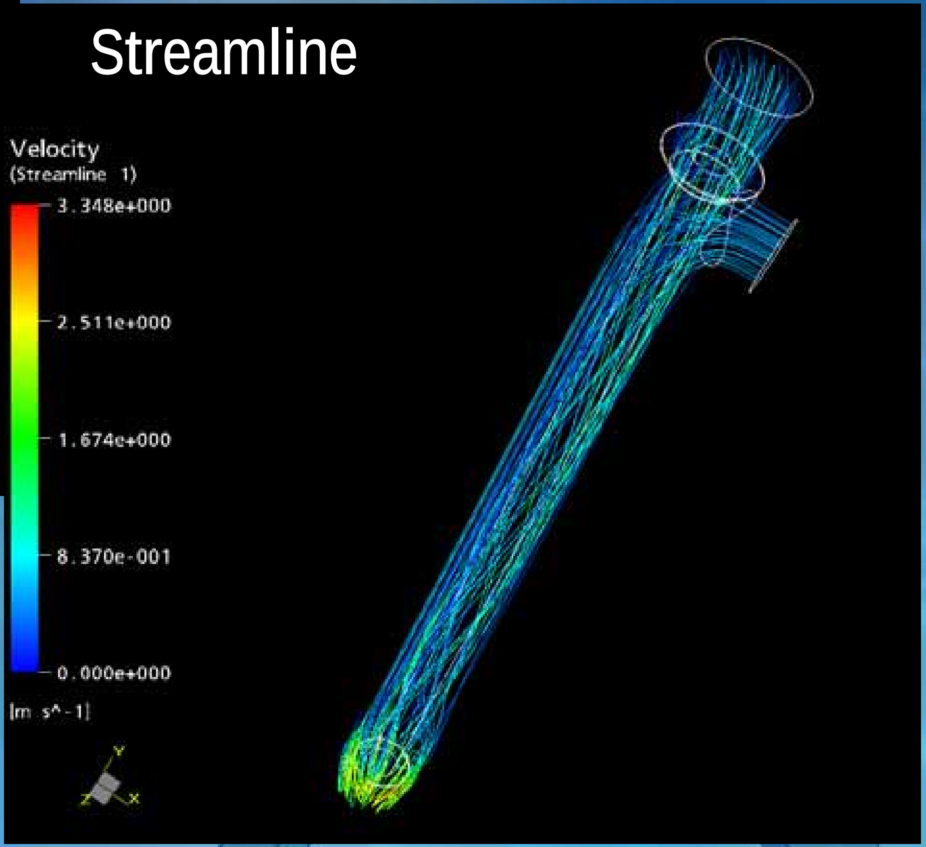
- Heat Flux: 3183 kW/m^2

Iteration Number: 1000

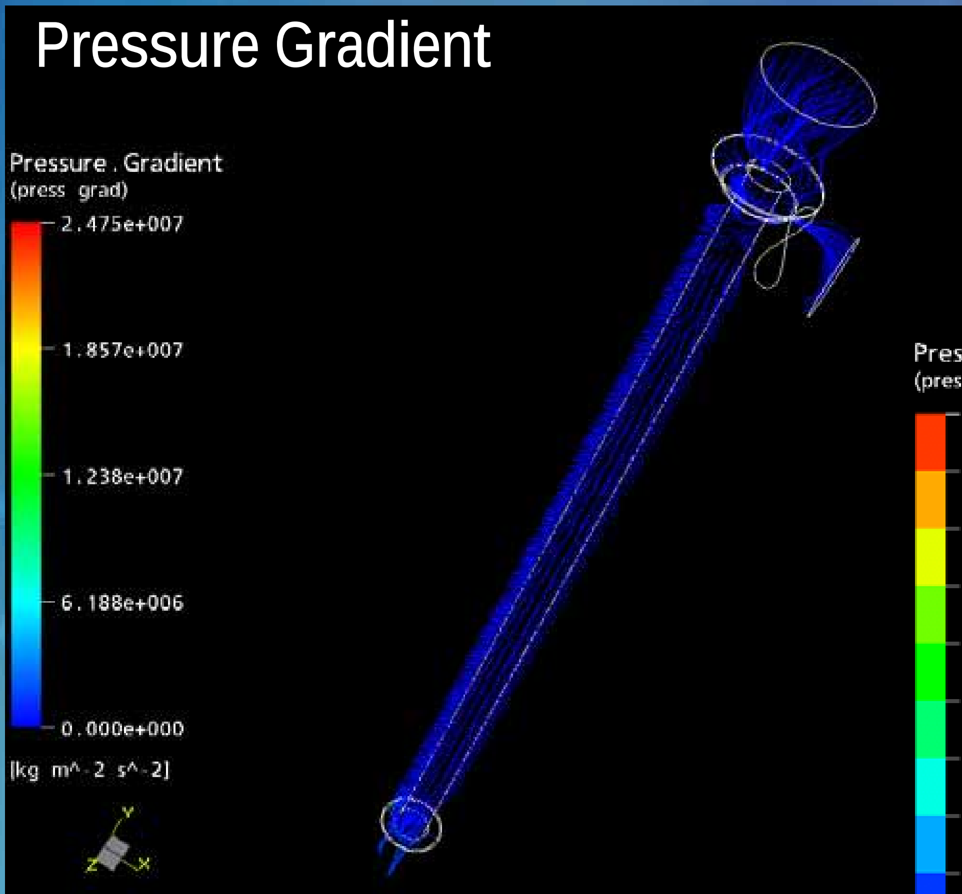
Residual: 0.00001

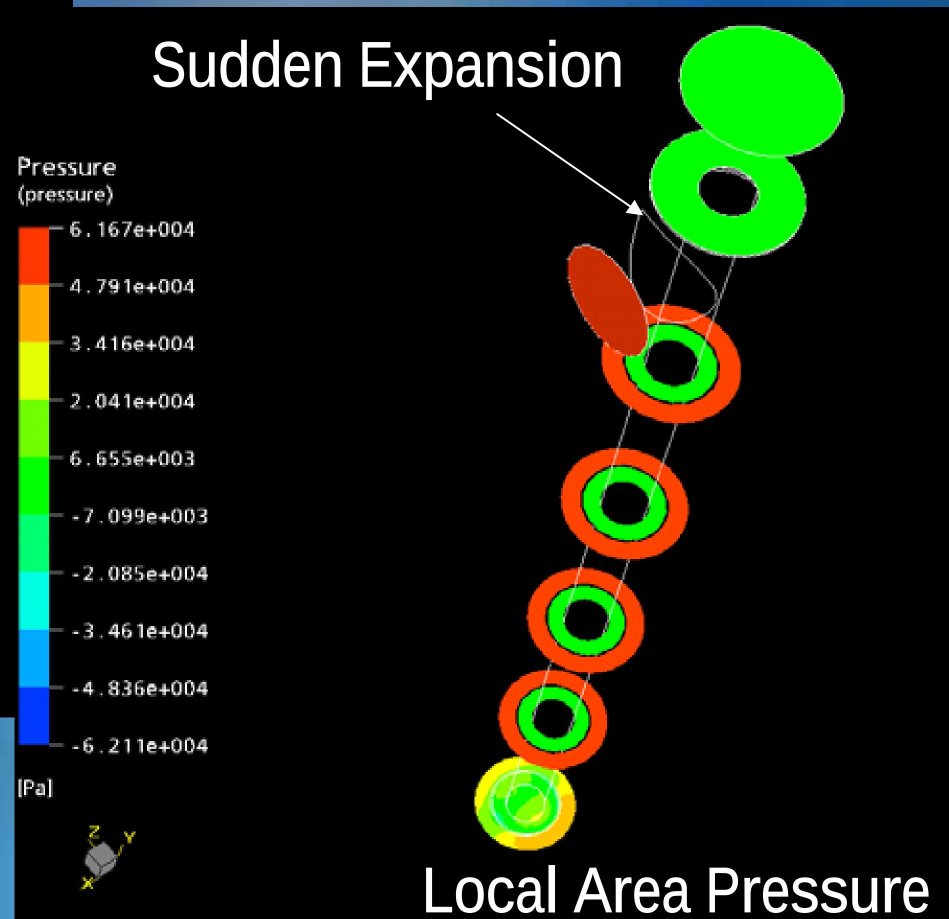
Result - Velocity





Result - Pressure





Result - Temperature